This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

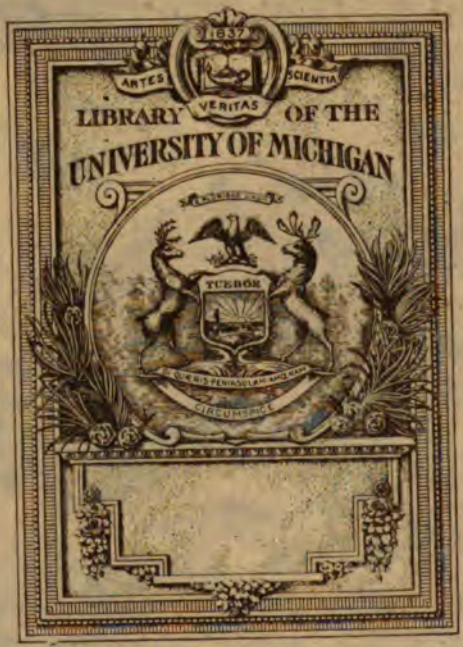
+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

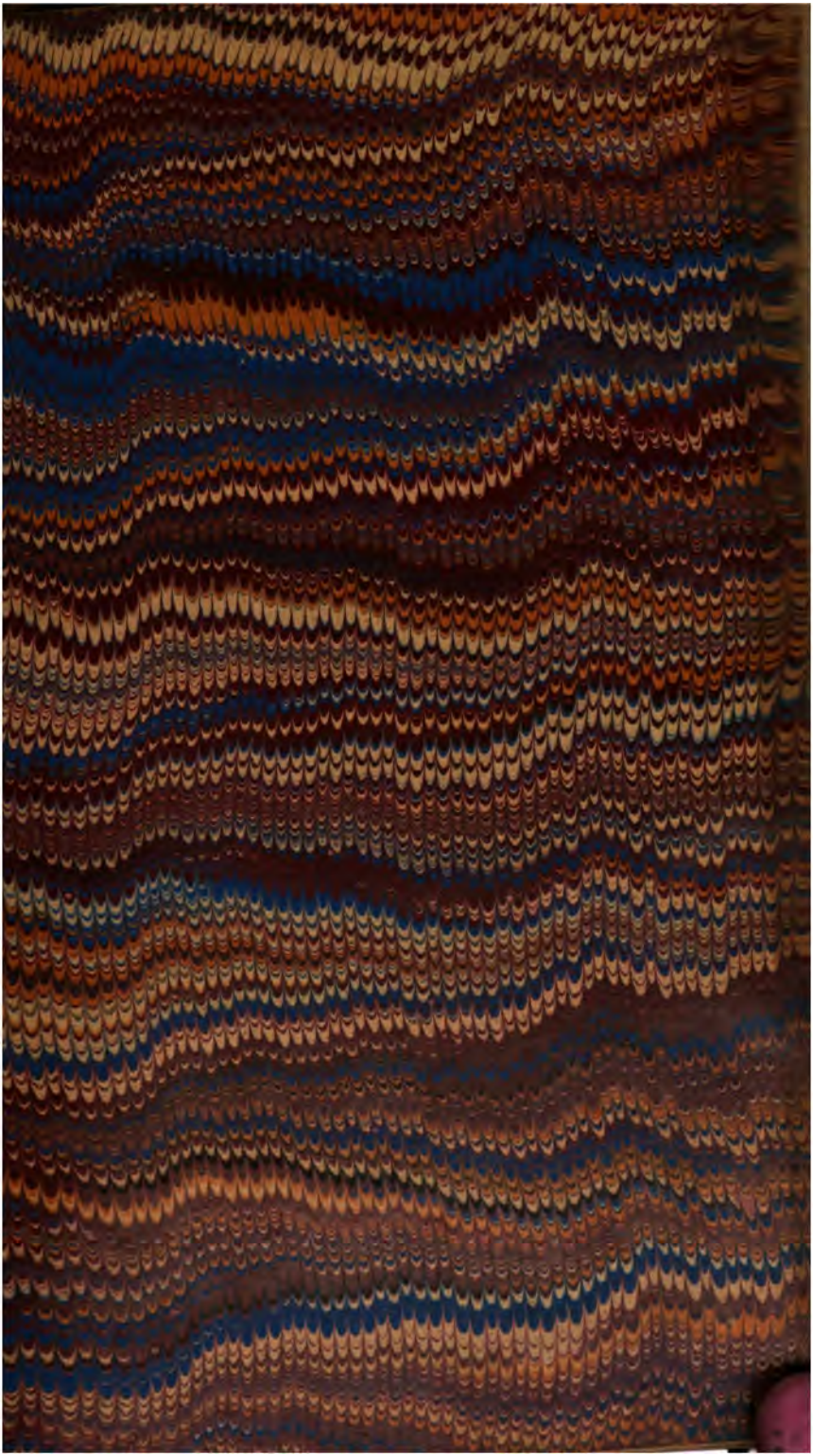
+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`


1837
ARTES
VERITAS
SCIENTIA
LIBRARY OF THE
UNIVERSITY OF MICHIGAN
TUEBOR



SCIENCE LIB.
S
218
.H3

THE

ROTHAMSTED MEMOIRS

ON

AGRICULTURAL CHEMISTRY

AND

PHYSIOLOGY.

BY

SIR JOHN BENNET LAWES, BART., LL.D., F.R.S., F.C.S., &c.,

OF ROTHAMSTED, HERTS,

AND

PROFESSOR JOSEPH HENRY GILBERT., LL.D., F.R.S., V.P.C.S., &c.

VOLUME VI.

CONTAINING REPORTS OF

FIELD EXPERIMENTS,
EXPERIMENTS ON VEGETATION,

&c., &c.

PUBLISHED 1884—1890 INCLUSIVE.

LONDON:

PRINTED BY DUNN AND CHIDGEY, 155-7, KINGSLAND ROAD, N.E.

1890.

ROTHAMSTED MEMOIRS.

CONTENTS OF VOL. VI.

REPORTS OF FIELD EXPERIMENTS, EXPERIMENTS ON VEGETATION, &c., &c.

Published

1. Introduction to the study of the Scientific Principles of Agriculture; being The Inaugural Lecture, delivered May 6, 1884, at the University Museum, Oxford 1884

2. On the Composition of the Ash of Wheat-Grain, and Wheat-Straw, grown at Rothamsted, in different Seasons, and by different Manures (Jour. Chem. Soc., vol. xlv., p. 305. August 1884) ... 1884

3. Report of Experiments on the growth of Wheat, for the second period of twenty years in succession on the same Land (Jour. Roy. Ag. Soc. Eng., vol. xx., s.s., part 2, p. 391.) 1884

4. On some points in the Composition of Soils; with Results illustrating the sources of the Fertility of Manitoba Prairie Soils (Brit. Ass. for the Advancement of Science. Montreal, September 2, 1884; Abstract Rep. Brit. Ass. for 1884, page 686. Full Paper—Trans. Chem. Soc., vol., xlvii. p. 380, June 1885) 1884-1885

5. On Agricultural Investigation: illustrated by Results of Experiments at Rothamsted, on the Growth of Wheat, for forty years in succession on the same Land. Being a Lecture delivered at the Michigan State Agricultural College, Lansing, Mich., October 14, 1884; and at Rutger's College, New Brunswick, N. J., October 27. 1884 1885

6. Note on some conditions of the Development, and of the Activity, of Chlorophyll—Abstract (Report of the Brit. Ass. for the Advancement of Science, 1885) 1885

7. On the Valuation of Unexhausted Manures (Jour. Roy. Ag. Soc. Eng., vol. xxi., s.s., part 2, p 590.) 1885

8. Results of Experiments at Rothamsted, on the Growth of Barley, for more than thirty years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iii., part 1.) ... 1886

9. Remarques sur la relation qui existe entre les sommes de température et la production agricole (Archives des Sciences physiques et naturelles, Troisième période, Tome xvi., No. 11, 15 Novembre, 1886) 1886

338566

Published

10. The Home Produce, Imports, Consumption, and Price of Wheat, in the United Kingdom, Thirty-four Harvest years, 1852-3 to 1885-6 ('The Field,' February 12, 1887) 1887

11. On the present Position of the Question of the Sources of the Nitrogen of Vegetation, with some new Results, and preliminary Notice of new Lines of Investigation.—Preliminary Notice (Proc. Roy. Soc., vol. xliii., p. 108.) 1887

12. Results of Experiments at Rothamsted, on the Growth of Root-crops, for many years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iii., part V.) 1887

13. Results of Experiments at Rothamsted, on the Growth of Potatoes, for twelve years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iv., part II.) 1888

14. The History of a Field newly laid down to Permanent Grass (Jour. Roy. Ag. Soc., Eng., vol. xxv., s.s., part I., 1889) 1889

15. Results of Experiments at Rothamsted, on the Growth of Leguminous Crops, for many years in succession on the same Land (Agricultural Students' Gazette, New Series, vol. iv., parts V. and VI.) 1889-1890

16. New Experiments on the Question of the Fixation of Free Nitrogen.—Preliminary Notice (Proc. Roy. Soc., vol. 47, p. 85.) ... 1890

17. The Food of our Agricultural Crops (Jour. Roy. Ag. Soc., Eng., vol., I., t.s., part I., 1890) 1890

INTRODUCTION

TO THE STUDY OF

THE SCIENTIFIC PRINCIPLES

OF

AGRICULTURE;

BEING

The Inaugural Lecture,

DELIVERED MAY 6, 1884,

AT THE UNIVERSITY MUSEUM, OXFORD,

BY

JOSEPH HENRY GILBERT, M.A., PH.D., LL.D.,

SIBTHORPIAN PROFESSOR OF RURAL ECONOMY IN THE UNIVERSITY OF OXFORD;

Vice-President of the Chemical Society; Fellow of the Royal, Linnean, and Royal Meteorological Societies; Honorary Member of the Royal Agricultural Society of England, of the Chemico-Agricultural Society of Ulster, and of the Academy of Agriculture and Forestry of Petrovskoie; Corresponding Member of the Institute of France (Academy of Sciences), of the Society of Agriculturists of France, and of the Agricultural Institute of Gorigoretsk; Chevalier du Mérite Agricole (France); and Gold Medallist of Merit for Agriculture (Emperor of Germany).

LONDON: HENRY FROWDE,

OXFORD UNIVERSITY PRESS WAREHOUSE, AMEN CORNER, E.C.

1884.

INAUGURAL LECTURE.

OXFORD, MAY 6, 1884.

MR. VICE-CHANCELLOR AND GENTLEMEN,

THE term *Rural Economy*, which gives the title to the Professorship to which I have been appointed, might be held to include such a variety of topics, that if I had no other guide in the selection of subjects to bring before you, I should be placed in a position of some difficulty. It would not be inappropriate to treat of the general management of landed property from the point of view of the Land-owner or the Land-agent; of the practical details of farming, mechanical, economical, and commercial, such as are essential to be observed by the tenant or occupier, if his business is to be a profitable one; or, lastly, attention might be confined to the elucidation of the scientific principles involved in successful practice, so far as the existing knowledge of the day permitted.

Fortunately, however, I have not only the obvious intentions of the Founder of this Chair, the late Professor Sibthorp, and the way in which my Predecessor, the late Professor Daubeny, interpreted and performed the duties of the office, to guide and limit my selection of subjects; but, on the 14th of July last, these duties were, under the sanction of the Chancery Division of the High Court of Justice, defined to be to lecture on the *Scientific Principles of Agriculture.*

It may be not out of place to remind you that, according to Dr. Sibthorp's will, the Sherardian Professor of Botany for the time being was to hold the Professorship of Rural Economy; and that hitherto,

that is until the settlement by the Court of Chancery last year, the appointment has been so held ; and the obligation was limited to giving one Public Lecture in each term. The new arrangement, however, dissociates the Chair of Rural Economy from that of Botany, and requires that twelve lectures shall be given annually.

Thus my responsibilities are somewhat defined, and they are, at the same time, somewhat limited :—for, how far from a complete system of instruction in all that pertains to Rural Economy can be embodied in a course of twelve lectures may be judged by reference to the course of study laid down in Institutions specially devoted to the training of Students in Agriculture. Thus, the Syllabus of one Agricultural College includes no less than thirty distinct subjects of lecture or other instruction, and the Prospectus of another enumerates sixteen main departments, covering much the same range of subjects as the other ; whilst each Institution has a numerous staff of Professors or Teachers. Again, in one London College a course of forty lectures is annually given on Soils, Manures, Crops, Live Stock, &c.; and in another lectures and laboratory instruction are given on Soils, Rotation, Manures, Feeding and Feeding-stuffs, Seeds, &c.

It is not then, I take it, expected of me that I should undertake to impart that systematic instruction in the various branches of the art and the science of Agriculture, which it is desirable the student who intends to devote himself to the details of practical farming, whether as agent or occupier, should receive. I assume that those studying at this University will for the most part be interested in land either as Owners, or as Clergymen in rural districts, or it may be as Statesmen, and that it should be my endeavour so to inculcate general principles as to train the

observation, and give a direction to the reflections, of those who hear me, and to enable, and it may be to stimulate them, to study further for themselves, as problems requiring it may come before them.

What then is Agriculture—the scientific principles of which we have to investigate? Discarding the mere etymological meaning of the term, and giving it the wider signification accorded to it by long usage, it is the art by which animal as well as vegetable products are obtained from the land.

Natural vegetation, as in the case of prairie-lands, for example, does indeed contribute food to the lower animals, and through them food and other products for the use of man; but the result is attained with little of his aid which can come under the definition of Agriculture.

But the practices by which vegetable and animal products are obtained from the land in settled countries differ essentially from those above alluded to, and it is these to which our attention must mainly be directed. Such Agriculture implies the growth of other plants than would be obtained under conditions of natural vegetation, and the growth of more produce over a given area than would be so obtained. It implies, in fact, what may be called concentrated production.

Agriculture, the oldest of the arts, was in methods at first purely mechanical; though, as we now know, the results to be attained were largely chemical. When manure was first applied to the soil, that is when the refuse of previous crops, or the excrements of animals, were first returned to the land as a means of increasing the growth of succeeding crops, directly chemical means—the supply of material—were first adopted.

Professor Daubeny, in his lectures on Roman Agriculture, quotes Cato as having said—

'If I am asked, what is the first point in good husbandry, I answer, good ploughing; what the second, ploughing of any kind; what the third, manuring.'

We have thus evidence of the relatively little esteem in which manuring was held in Italy two thousand years ago; and in the fact that so much more value was set upon the mechanical operations we have evidence that the resources of the soil itself were far from being exhausted, and only required such means to be taken to render them available.

There is nevertheless evidence that, long before the time of Cato, it was sought to restore fertility to the soil by practices the efficacy of which is still fully recognised; though the explanation of some of the phenomena involved is still a matter of controversy. Such, for example, was the growth of various crops of the Leguminous family, sometimes to be in great part removed, but in others to be at once ploughed into the land, by either of which methods the growth of succeeding crops was enhanced. This subject will receive detailed consideration further on.

But although manuring, in various ways, has thus been so long recognised as desirable, it is in fact only in quite recent times that the rationale of such practices could be at all satisfactorily explained. To this end it was obviously essential not only to know the composition of the vegetable products grown, but something of the sources of their various constituents —whether these must be derived from the soil, or whether from the atmosphere, or from water?

What then is the composition, and what are the sources of the constituents of vegetable products?

When a vegetable (or animal) substance is burnt,

the greater part of it is dissipated, but there remains a white ash. This ash is found on analysis to contain most or all of the constituents enumerated in the first column of the following Table.

Constituents of Plants and Animals.

Incombustible or Fixed.	Combustible or Volatile.
Iron.	Carbon.
(Manganese).	Hydrogen.
Lime.	Oxygen.
Magnesia.	Nitrogen.
Potash.	
Soda.	
Phosphoric acid.	
Sulphuric acid.	
Chlorine.	
Silica.	
	Sulphur.
	Phosphorus.

Rarer substances than these are also sometimes found. It will be my duty, in subsequent lectures, to call your attention in some detail to what is known as to the occurrence, and the offices, of the various mineral or ash-constituents in plants. It will suffice here to say, that the ash of one and the same description of plant, growing on different soils, may, so long as it is in the vegetative or immature state, differ very much in composition. Again, the ashes of different species, but growing on the same soil, will differ very widely in the proportion of their several constituents. But it is found that the nearer we approach to the elaboration of the final products of the plant—the seed for example—the more fixed is the composition of the ash of such products of one and the same species. In other words, there is very

little variation in the composition of the ash of one and the same description of seed, or other final product, provided it be evenly and perfectly matured. This fact alone, independently of what has been established of late years in regard to the office or function so to speak of individual mineral constituents of plants, would be sufficient to indicate the essentialness of such constituents for healthy growth.

Th. De Saussure, in his work entitled, 'Recherches sur la Végétation,' published in 1804, gave the results of the analyses of many plant-ashes, maintained the essentialness of the ash-constituents, and pointed out that they must be derived from the soil. He also called attention to the probability that the incombustible constituents so derived by plants from the soil were the source of those found in the animals which fed upon them.

Yet such was the prevailing uncertainty on the point, that Sir Humphrey Davy, in his lectures delivered not long afterwards, deemed it not inappropriate to combat the idea that the earths found in plants had been formed from any of the elements existing in the air, or in water. After quoting the results of an experiment of his own, in which he attempted to grow oats without any supply of silica beyond that contained in the seed sown, and referring to the experiments of De Saussure, he says:—

'As the evidence on the subject now stands, it seems fair to conclude, that the different earths and saline substances found in the organs of plants are supplied by the soils in which they grow; and in no cases composed by new arrangements of the elements in air or water.'

It is no longer doubted that the mineral or ash-constituents of plants must be provided within the

soil, either from its own natural resources, or by means of manure. It will be seen, however, from the facts just stated, how very recently fixed ideas on the subject have been arrived at.

Then, as to the combustible or volatile constituents which are expelled in the incineration—the carbon, the hydrogen, the oxygen, and the nitrogen. From what we now know of the sources of these constituents of plants, it is obvious that a knowledge of the composition of the atmosphere and of water was essential to any true conception of the main features of the vegetative process, and it was only towards the end of the last century that the composition of the air, and of water, and their mutual relations with vegetation, were first pointed out.

I shall have to go into these matters in some detail in subsequent lectures, but I would here observe that it is to the collective labours of Black, Scheele, Priestley, Lavoisier, Cavendish, and Watt, that we owe the knowledge that common air consists of nitrogen and of oxygen, with a little carbonic acid; that carbonic acid itself is composed of carbon and of oxygen; and that water is composed of hydrogen and oxygen; whilst Priestley and Ingenhousz, Sennebier and Woodhouse, investigated the mutual relations of these bodies and vegetable growth.

Thus, Priestley observed that plants possessed the faculty of purifying air vitiated by combustion, or by the respiration of animals; and he having discovered oxygen, it was found that the bubbles which Bonnet had shown to be emitted from the surface of leaves immersed in water consisted chiefly of that gas. Ingenhousz demonstrated that the action of light was essential to the development of these phenomena, and Sennebier proved that the oxygen

evolved resulted from the decomposition of the carbonic acid taken up.

So far, attention had been more prominently directed to the influence of plants upon the media with which they were surrounded, than to that of those media in contributing to the increased substance of the plants themselves.

It was, too, towards the end of the last century, and in the beginning of the present one, that De Saussure followed up these enquiries; and, in his work already alluded to, he may be said to have indicated, if not indeed established, some of the most important facts with which we are yet acquainted regarding the sources of the constituents of the growing plant. He illustrated experimentally, and even to a certain extent quantitatively, the fact that in sun-light plants increase in carbon, hydrogen, and oxygen, at the expense of carbonic acid and of water; and in his main experiment on the point he found the increase in carbon, and in the elements of water, was very closely in the proportion in which they are known to exist in the chief non-nitrogenous constituents of plants, the carbohydrates—starch, gum, sugar, cellulose, etc.

With regard to the nitrogen which plants had already been shown to contain, Priestley and Ingenhousz thought their experiments indicated that they absorbed free nitrogen from the atmosphere; but Sennebier and Woodhouse arrived at an opposite conclusion. De Saussure, again, thought that his experiments showed rather an evolution of nitrogen at the expense of the substance of the plant than any assimilation of it from gaseous media. He further concluded that the source of the nitrogen of plants was more probably the nitrogenous compounds

within the soil, and the small amount of ammonia which he demonstrated to exist in the atmosphere.

Upon the whole, De Saussure concluded that air and water contributed a much larger proportion of the dry substance of plants than did the soils in which they grew. In his view a fertile soil was one which yielded liberally to the plant nitrogenous compounds, and the incombustible or mineral constituents; whilst the carbon, hydrogen, and oxygen, of which the greater proportion of the dry substance of the plant was made up, were at least mainly derived from the air and water.

From what has been stated, it will be seen that anything like a consistent scientific explanation of vegetable and animal production was impossible until comparatively very recent times. In fact it is clear that agricultural chemistry properly so called is not a century old; whilst, without a knowledge of it, the scientific principles of agriculture could not be taught.

What then is agricultural chemistry? It is the chemistry of the soil, the chemistry of the atmosphere, the chemistry of vegetation, and the chemistry of animal life and growth, in their bearings on agricultural production.

Obviously vegetable and animal physiology are essential elements in the explanation of many of the phenomena of agricultural production; but for anything more than necessary passing reference to these branches of science you must look to the distinguished Professors of Physiology and Botany now attached to this University.

To Sir Humphrey Davy we owe the first systematic attempt to apply scientific principles to the elucidation and improvement of agricultural practice.

Each year, for ten successive years, from 1802 to 1812, he delivered a course of lectures which, in 1813, were published in a work entitled, 'Elements of Agricultural Chemistry,' which he finally revised for the fourth edition in 1827, but which has gone through several editions since.

In those lectures Sir Humphrey Davy passed in review and correlated the then existing knowledge, both practical and scientific, bearing upon agriculture. He treated of the influences of heat and light; of the organisation of plants; of the difference, and the change, in the chemical composition of their different parts; of the sources, composition, and treatment of soils; of the composition of the atmosphere, and its influence on vegetation; of the composition and the action of manures; of fermentation and putrefaction; and, finally, of the principles involved in various recognised agricultural practices.

Concurrently with the delivery and the publication of Davy's Lectures in England, the most prominent writer on the scientific principles of agriculture on the continent was Thaer. In 1810 he published a work entitled 'Principes Raisonnés d'Agriculture,' and for some years afterwards contributed papers on some special points. He considered that the fertility of the soil depended on the amount and character of the humus it contained; it being, in his view, the only substance, excepting water, that yielded aliment to plants. He pointed out that it was the residue of previous vegetation, containing carbon, hydrogen, oxygen, and nitrogen, associated with phosphorus, sulphur, and some salts. He quotes De Saussure as having shown that humus contains a lower percentage of oxygen and higher percentages of carbon and nitrogen than the plants from which it has been

produced. He states that its composition varies according to the access of oxygen and water; that it absorbs oxygen, and gives out carbonic acid, which supplies nourishment to plants; also, that it yields soluble extractive matter again and again by time and exposure. He further states that the more the decomposition has proceeded, the more refractory, and the less active and useful for vegetation, is the residue.

With the exception of the discourses of Sir Humphrey Davy, and the writings of Thaer, the subject seems to have received comparatively little attention, nor was any other addition of importance made to our knowledge in regard to it, during a period of more than twenty years, from the date of the appearance of De Saussure's work in 1804.

From about 1825 to 1840, Dr. Carl Sprengel, formerly Professor of Agriculture at Brunswick, published a series of about thirty papers in connection with agriculture, and agricultural chemistry. These memoirs covered a wide range of subjects, and recorded the results of numerous investigations by the author himself. Among them may be mentioned investigations on humus, humic acid, and humates; on the constituents of some surface soils and subsoils; on the composition of various kinds of straw, and their value as food and litter; on the amount of potash in granites, and other rocks; on the ash-constituents of cereal grains, &c. Lastly, he published a general treatise on manures, including a chapter on animal manures, in which he gives the results of the analysis of the solid and liquid excretions of the various animals of the farm, and, among other points, insists upon the value as manure of the ammonia yielded by such materials.

Professor Schübler, of Tübingen, also published

a Work entitled, 'Grundsätze der Agricultur-Chemie,' a second and revised edition of which was brought out in 1838, by Professor Krutzsch, of Tharand. In this Work the physical and chemical properties of soils are discussed in much detail; and the results of numerous investigations on the subject by the author himself are given.

Boussingault, who had previously published numerous papers, chiefly on chemical subjects, about 1834 became, by marriage, joint proprietor with his brother-in-law of the estate of Bechelbronn, in Alsace. His brother-in-law, M. Lebel, was both a chemical manufacturer and an intelligent practical farmer, accustomed to use the balance for the weighing of manure, crops, and cattle. Boussingault at once applied himself to Chemico-Agricultural research; and it was under these conditions of the association of 'Practice with Science' that the first laboratory on a farm was established.

From this time forward, Boussingault generally spent about half the year in Paris, and the other half in Alsace; and he has continued his scientific labours, sometimes in the city and sometimes in the country, up to the present time. I may here mention that I had the pleasure of seeing him well, and still actively interested in problems of agricultural science, at his Chateau in Alsace in the autumn of last year.

Boussingault's first important contribution to agricultural chemistry was made in 1836, when he published a paper on the amount of nitrogen in different foods, and on the equivalence of the foods, founded on the amounts of nitrogen they contained; and he compared the results so arrived at with the estimates of others founded on actual experience.

Although his conclusions on the subject have doubtless undergone modification since that time, the work itself marked a great advance on previously existing knowledge and modes of viewing the question.

In 1837 Boussingault published papers on the amount of gluten in different kinds of wheat; on the influence of the clearing of forests on the diminution of the flow of rivers; and on the meteorological influences affecting the culture of the vine. In 1838 he published the results of an elaborate research on the principles underlying the value of a rotation of crops. He determined by analysis the composition, organic and inorganic, of both the manures applied to the land, and the crops harvested. In his treatment of the subject he evinced a clear perception of the most important problems involved in such an enquiry; some of which, with the united labours of himself and many other workers, have scarcely yet received an undisputed solution.

Thus, in the same year (1838), he published the results of an investigation on the question whether plants assimilate the free or uncombined nitrogen of the atmosphere; and although the analytical methods of the day were inadequate to the decisive settlement of the point, his conclusions were in the main those which much subsequent work of his own, and much of others also, have served to confirm.

In subsequent lectures I shall have to refer in some detail to the various investigations here alluded to.

As a further element of the question of the chemical statistics of rotation, Boussingault determined the amount and composition of the residues of various crops; also the amount of constituents consumed in the food of a cow, and of a horse, respectively, and

yielded in the milk and excretions of the cow, and in the excretions of the horse. Here, again, the exigencies of the investigation he undertook were beyond the reach of the known chemical methods of the time. Indeed, rude as the art of agriculture is generally considered to be, the scientific elucidation of its practices requires the most refined and very varied methods of research; and a characteristic of the work, not only of Boussingault, but of most agricultural investigators, may be said to be, that they have frequently had to devise methods suitable to their purpose, before they could grapple with the problems before them.

In 1839, chiefly in recognition of his important contributions to agricultural chemistry, Boussingault was elected a member of the Institute of France; and in 1878, thirty-nine years later, the Council of the Royal Society awarded to him the Copley Medal, the highest honour at their disposal, for his numerous and various contributions to science, but especially for those relating to agriculture.

The foregoing brief historical sketch is sufficient to indicate, though but in broad outline, the range of existing knowledge on the subject of agricultural chemistry prior to the appearance of Liebig's memorable work, 'Organic Chemistry in its applications to Agriculture and Physiology,' the first edition of which was published in 1840.

It will be seen that some very important, and indeed fundamental, facts had already been established in regard to vegetation; first by the numerous investigations made about half a century previously, by which the composition of the atmosphere, and of water, and the mutual relations of these and vegetable growth,

had been determined; next by the labours of De Saussure, to which we owe a near approach to a quantitative representation of the phenomena of vegetation, which had thus far only been qualitatively observed. To De Saussure we also owe a clear perception of the importance, and of the sources, of both the nitrogen, and the ash-constituents, of plants. Then followed Davy, with the first attempt to give a systematic view of the relations of practice with science in agriculture; Thaer, who traced the fertility of soils to the residue of previous vegetation which they contained; Sprengel, who contributed much experimental result on various branches of the subject; and lastly Boussingault, who had not only still further extended experimental enquiry, but brought both his own and previous results to bear upon the elucidation of long-recognised agricultural practices.

There can be no doubt that the data supplied by the researches which have been referred to, and especially those of De Saussure, Davy, Thaer, Sprengel, and Boussingault, contributed important elements to the basis of established facts upon which Liebig founded his brilliant generalisations. Indeed, so obvious was this, that, in 1841, Dumas and Boussingault published, jointly, an essay which afterwards appeared in English under the title of 'The Chemical and Physiological Balance of Organic Nature,' which was, in fact, a sort of 'réclamation.'

Nor can there be any doubt that the appearance of Liebig's two works, 'Organic Chemistry in its applications to Agriculture and Physiology' in 1840, and 'Animal Chemistry, or Organic Chemistry in its applications to Physiology and Pathology' in 1842, constituted a very marked epoch in the history of the progress of Agricultural Chemistry. In the

treatment of his subject he not only called to his aid the previously existing knowledge directly bearing upon it, but he also turned to good account the more recent triumphs of organic chemistry, many of which had been won in his own laboratory. Further, a marked feature of his expositions was the adoption of the quantitative method of illustration, and argument.

But, notwithstanding the evidence afforded by the direct experiments of De Saussure and his predecessors, Vegetable Physiologists, and some others, continued to hold the view that the humus of the soil was the source of the carbon of vegetation. Liebig gave full weight to the evidence of the experiments of De Saussure and others; he illustrated the possible or probable transformations within the plant by facts already established in organic chemistry; and he demonstrated the impossibility of the humus of the soil supplying the amount of carbon assimilated over a given area. He pointed out, that humus itself was the product of previous vegetable growth; that it could not therefore be an original source of the carbon; and that, from the degree of its insolubility, either in pure water or in water containing alkaline or earthy bases, only a small portion of the carbon assimilated by plants could be derived from the amount of humus that could possibly enter the plant in solution. He maintained that, so far as humus was beneficial to vegetation at all, it was only by its oxidation, and a consequent supply of carbonic acid within the soil; a source which he considered only of importance in the early stages of the life of a plant, and before it had developed, and exposed to the atmosphere, a sufficient amount of green surface to render it independent of soil-supplies of carbonic acid.

In subsequent lectures, evidence will be adduced showing that Liebig was certainly right, in concluding that humus is not an adequate source of the carbon of our crops. It will be seen that, to some of them at any rate, it is at most only a very limited source, if indeed it is to them a source at all. It will, on the other hand, be shown that the organic residue of previous vegetation accumulated in the soil is, to say the least, a very material source of the nitrogen of our crops.

Thus, though mistaken as to the explanation of the fertility of soils rich in humus, Thaer and others were, after all, not far from the truth when they maintained that the richness of a soil in such matter in a condition readily susceptible to oxidation, was, in a great degree, the measure of its fertility.

With regard to the hydrogen of plants, at any rate that portion of it contained in their non-nitrogenous products, Liebig maintained that its source must be water; and that the source of the oxygen was either that contained in carbonic acid, or that in water.

With regard to the nitrogen of vegetation, both from the known characters of free nitrogen, and as he considered a legitimate deduction from direct experiments, Liebig argued that plants did not assimilate uncombined nitrogen, either from the atmosphere, or dissolved in water and so absorbed by the roots. The source of the nitrogen of vegetation was, he maintained, *ammonia*; the product of the putrefaction of one generation of plants and animals affording a supply for its successors. He pointed out that, in the case of a farm receiving nothing from external sources, and selling off certain products, the amount of nitrogen in the manure produced by the consumption of some of the vegetable produce on

the farm itself, together with that due to the refuse of the crops, must always be less than was contained in the crops grown. He concluded that, although the quantity returned to the land as manure was important, a main source of the nitrogen assimilated over a given area was the ammonia brought down from the atmosphere in rain.

There can be no doubt that, owing to the limited and defective experimental evidence then at command on the point, Liebig at that time (as he did afterwards) greatly over-estimated the amount of combined nitrogen available to vegetation from that source.

In Boussingault's 'réclamation' already referred to, he gave much more prominence to the importance of the nitrogen of manures. In Liebig's next edition (in 1843) he combated the notion of the relative importance of the nitrogen of manures. He maintained, in opposition to the view put forward in his former edition, that the atmosphere afforded a sufficient supply of combined nitrogen not only for natural vegetation, but for cultivated plants; that this supply was sufficient for the cereals as well as for leguminous plants; that it was not necessary to supply nitrogen for the former; and he insisted very much more strongly than formerly, on the relative importance of the supply of the incombustible, or, as he designated them, the 'inorganic' or 'mineral,' constituents.

Many determinations of the amount of combined nitrogen brought down in rain have been made, in different countries, since the date here referred to; and in a subsequent lecture it will be shown that the amount so available to the vegetation of a given area is very much less than was assumed by Liebig, or has generally been supposed.

As to the incombustible, or, as he designated them, the '*mineral*' constituents, Liebig adduced many illustrations in proof of their essentialness. He called attention to the variation in the composition of the ash of plants grown on different soils; and he assumed a greater degree of mutual replaceability of one base by another, or of one acid by another, than could now be admitted. He traced the difference in the mineral composition of different soils to that of the rocks which had been their source; and he seems to have been led by the consideration of the gradual action of '*weathering*,' in rendering available the otherwise locked-up stores, to attribute the benefits of *fallow* exclusively to the increased supply of the incombustible or mineral constituents which would, by its agency, be brought into a condition in which they could be taken up by plants.

It will be seen further on, how very materially subsequently acquired experimental evidence has tended to modify our views as to the explanation of the benefits of fallow.

The benefits of an alternation of crops, Liebig considered to be in part explained by the influence of the excreted matters from one description of crop upon the growth of another. He did not attach weight to the assumption that such matters would be directly injurious to the same description of crop; but he supposed rather that the matters excreted by a plant were those which it did not need, and that they would therefore be of no avail to the same description of plant, but would be of use to others. He, however, attributed much of the benefits of a rotation, to different mineral constituents being required from the soil by the different crops.

Since the enunciation of these views, very much

direct experimental evidence bearing upon the rationale of rotation has been acquired, and it will be my duty to lay it before you in some detail.

Treating of *manure*, Liebig laid the greatest stress on the return by it of the potass and the phosphates removed by the crops. But, in his first edition, he also insisted on the importance of the nitrogen, especially that in the liquid excretions of animals, and condemned the methods of treatment of animal manures by which the ammonia was allowed to be lost by evaporation. It is curious, and significant, however, that some of the passages in that edition, in which he the most forcibly urges the value of the nitrogen of animal manures, are omitted in the third and fourth editions.

In his second work, that on *Animal Chemistry*, published in 1842, Liebig discussed two subjects of much interest and practical importance to the agriculturist:—namely, the sources in the food of the fat stored up in the animal body, and the characteristic food requirements of the animal organism induced by the exercise of force.

To render the points here at issue intelligible, it is necessary to remind you that the constituents of food, both vegetable and animal, may broadly be classed into those containing nitrogen, and those not containing it—in other words, into the nitrogenous, and the non-nitrogenous constituents.

From the nitrogenous constituents of the food, the nitrogenous constituents of the animal body—the membranes and cellular tissue, the nerves and brain, cartilage, and the organic part of bones—must be derived. It is admitted that by oxidation and transformation within the body, some of these nitro-

genous matters may yield fat, with other products, such as urea which passes off by the urine, and carbonic acid which passes off by respiration.

The non-nitrogenous constituents of the food on the other hand—the fatty matters, and the so-called carbohydrates—starch, sugar, cellulose, &c., are supposed to be the chief sources of the carbonic acid respired, and hence have sometimes been classed as the respiratory constituents of food.

The questions arise—Is the non-nitrogenous substance *fat*, which is stored up in the feeding of the herbivora, derived chiefly from the nitrogenous matters of the organs, or in the circulation, or from the non-nitrogenous matters of the food, the carbohydrates? Then, again, in the exercise of force, is the increased amount of the products of oxidation eliminated from the body chiefly due to an increased transformation of the nitrogenous substance of the tissues and fluids, or of the non-nitrogenous constituents—the fat of the body, or of the food, and the carbohydrates?

In reference to the sources of the fat of the animal body, Liebig maintained that the vegetable food consumed by herbivora did not contain anything like the amount of fat which they stored up in their bodies; and he showed how nearly the composition of fat was obtained by the simple elimination of so much oxygen, or of oxygen and a little carbonic acid, from the various carbohydrates of the vegetable food—starch, sugar, &c. Much less oxygen would be required to be eliminated from the nitrogenous constituents, such as fibrine, &c., than from a quantity of carbohydrate containing an equal amount of carbon. The formation of fatty matter in plants was of the same kind; it was the result of

a secondary action, starch being first formed from carbonic acid and water.

Referring to the exercise of force, he argued that the animal secretions must contain the products of the metamorphosis of the tissues; he concluded that a starving man, with severe exertion, would secrete more urea than the most highly fed individual in a state of rest; and he combated the idea that the nitrogen of the food can pass into urea without having previously become part of an organised tissue. He said:—

'As an immediate effect of the manifestation of mechanical force, we see that a part of the muscular substance loses its vital properties, its character of life; that this portion separates from the living part, and loses its capacity of growth and its power of resistance. We find that this change of properties is accompanied by the entrance of a foreign body (oxygen) into the composition of the muscular fibre * * *; and all experience proves, that this conversion of living muscular fibre into compounds destitute of vitality is accelerated or retarded according to the amount of force employed to produce motion. Nay, it may safely be affirmed, that they are mutually proportional; that a rapid transformation of muscular fibre, or, as it may be called, a rapid change of matter, determines a greater amount of mechanical force; and conversely, that a greater amount of mechanical motion (of mechanical force expended in motion) determines a more rapid change of matter.'

Again:—

'The change of matter, the manifestation of mechanical force, and the absorption of oxygen, are, in the animal body, so closely connected with each other, that we may consider the amount of motion,

and the quantity of living tissue transformed, as proportional to the quantity of oxygen inspired and consumed in a given time by the animal.'

And again:—

'The production of heat and the change of matter are closely related to each other; but although heat can be produced in the body without any change of matter in living tissues, yet the change of matter cannot be supposed to take place without the co-operation of oxygen.'

Further, on the same point:—

'The sum of force available for mechanical purposes must be equal to the sum of the vital forces of all tissues adapted to the change of matter.'

'If, in equal times, unequal quantities of oxygen are consumed, the result is obvious, in an unequal amount of heat liberated, and of mechanical force.'

'When unequal amounts of mechanical force are expended this determines the absorption of corresponding and unequal quantities of oxygen.'

Then, more definitely still, referring to the changes which take place coincidently with the exercise of force, and to the demands of the system for repair accordingly, he says:—

'The amount of azotised food necessary to restore the equilibrium between waste and supply is directly proportional to the amount of tissues metamorphosed.'

'The amount of living matter, which in the body loses the condition of life, is, in equal temperatures, directly proportional to the mechanical effects produced in a given time.'

'The amount of tissue metamorphosed in a given time may be measured by the quantity of nitrogen in the urine.'

'The sum of the mechanical effects produced in

two individuals, in the same temperature, is proportional to the amount of nitrogen in their urine; whether the mechanical force has been employed in voluntary or involuntary motions, whether it has been consumed by the limbs or by the heart and other viscera.'

Thus, apparently influenced by the physiological considerations which he had adduced, and notwithstanding that in some passages he seemed to recognise a connection between the total quantity of oxygen inspired and consumed, and the quantity of mechanical force developed, Liebig nevertheless very prominently insisted that the amount of muscular tissue transformed—the amount of nitrogenous substance oxidated—was the measure of the force generated. He accordingly draws the conclusion, that the requirement for the nitrogenous constituents of food will be increased in proportion to the increase in the amount of force expended.

It will be obvious that the question whether, in the feeding of animals for the exercise of mechanical force, that is, for their labour, the demands of the system will be proportionally the greater for the nitrogenous, or for the non-nitrogenous constituents of food, is one of considerable interest and practical importance.

In reference to this point, to that of the sources in the food of the fat of the animal body, as well as to the requirements for the different constituents of food for the maintenance, and for the general increase, of the body, in the feeding of the animals of the farm, a great deal of experimental evidence has been acquired during the last forty years, both in this country and on the Continent, and to this I shall have to refer in some detail on a future occasion.

So far, I have endeavoured to convey some idea of the state of knowledge bearing upon the scientific principles of agriculture, prior to the appearance of Liebig's first two works on the subject; and also briefly to summarise the views he then enunciated in regard to some points of chief importance. I will now attempt briefly to indicate what progress has been made since that period, largely at any rate due either to the direct influence of his teaching, or to the stimulus given to enquiry by the discussions which his writings called forth.

It is a coincidence of some interest, that the first lectures given by the Sibthorpian Professor of Rural Economy in this University, were delivered by my predecessor, the late Dr. Daubeny, almost contemporaneously with the appearance of Liebig's first Work, in 1840; one of a course of three having been given before, and two within a few months after, the publication of that work. These lectures were afterwards published, and, in his preface, Professor Daubeny expresses his indebtedness to Liebig's Work for some of the fundamental doctrines, and for some of the details embodied in his expositions.

In the lectures in question, Professor Daubeny discussed the importance of the study of botany, physiology, and chemistry, in the elucidation of agricultural practices. He contrasted the conditions of cultivation in the case of virgin soils, with those in long-settled countries. He treated of the sources of the constituents of our crops, of fallowing, manuring, and rotation, so far as the knowledge of the day permitted.

Finally, Dr. Daubeny put forward some speculations as to the origin of the constituents of the first vegetation on the surface of the globe, and

especially as to the source of the combined carbon, and the combined nitrogen, accumulated in the total existing vegetable and animal life and remains. He traced these to carbonic acid, and ammonia, evolved by volcanic action. It may be observed that one source of combined nitrogen is undoubtedly electrical action, especially in equatorial regions, but it will be seen further on, that so far as quantitative evidence is at command on the point, the amounts of combined nitrogen available from atmospheric sources over a given area, within a given time, are, at any rate in temperate latitudes, quite inadequate to account for the amounts recovered in crops over the same area, and in the same time. It will be seen too, that the question of the sources of the nitrogen of our crops, is one upon which very conflicting views are still entertained.

For a period of more than twenty-five years, Dr. Daubeny continued to give lectures from time to time on various branches of Rural Economy, generally with some reference to the discussions of the day.

But independently of discourses of this expository or critical kind, he, in 1845, described the results of some experiments he had made to elucidate the principles involved in the rotation of crops. To this end he had set apart a number of plots in the Botanic Garden, each 10 feet square. On some of these he grew the same description of plant year after year for several years in succession, whilst on others he alternated the different crops. The soil was admittedly not very favourable, being made ground, and the plots were very small. Still the results clearly showed that more produce was obtained from a given area when the different plants were grown in alternation, than when the same

description was grown successively. Subsequent examination of the soils further showed considerable differences, dependent on the exhaustion by the different crops.

Dr. Daubeny confined his illustrations and his discussions almost entirely to the mineral or ash-constituents of the crops; thus following the lines of argument current at the time. Although the facts brought out are of interest, all subsequently acquired evidence tends to show, that the benefits of rotation are not explicable by exclusive reference to the difference in the description, and amounts, of the mineral constituents which are taken up by the different crops.

Among the most notable of Professor Daubeny's lectures, was a course of eight on Roman Husbandry, which were afterwards published.

These lectures evince considerable historical research, and are of much interest independently of the facts relating to the Agriculture of the Ancients which they bring to light. But their chief interest to the agricultural student of the present day is to be found in the evidence, discernible between the lines, that certain practices then adopted for the increase of the products obtained from the land, are still recognised as effective, though, in some cases, the precise explanation of the benefits derived yet remains a matter of controversy. Thus, although no fixed rotations of crops seem to have been adopted, yet the occasional growth of plants of the Leguminous family was had recourse to, and recognised as a means of increasing the growth of the gramineous crops with which they were alternated.

Again, the evidence of both Columella and Virgil goes to show, that the fertility of soils was then attributed to the accumulations from previous natural

vegetation, and that, as this store was gradually used up, the soils became poor.

Although, as has been said, the lectures which have been given by the Sibthorpian Professor of Rural Economy commenced almost simultaneously with the appearance of Liebig's first work, and many of them had direct reference either to Liebig's own views, or to current discussions relating to them, their inauguration was prior to, and quite independent of, the interest excited by that work. Not so was it, in the case of many other agencies for promoting knowledge in regard to the scientific principles of agriculture, both in this country, and on the Continents of Europe and America. I think too, I may safely say, that the stimulus was earlier felt, and was earlier productive of results, in this country, than in Liebig's own, or elsewhere.

In 1843, the Royal Agricultural Society of England first appointed a consulting Chemist; Dr., now Sir Lyon Playfair, being the first holder of the office. In 1848, the late Professor Way was elected, and the Society's journals of that time bear testimony to his clear perception of the agricultural problems requiring solution, and of his capacity as an investigator. In 1858, Dr. Voelcker succeeded to the office, and continues to hold it with much advantage to that union of 'Practice with Science,' which the Society by its motto recognises as so essential to progress. Thus, after having been Professor of Chemistry at the Royal Agricultural College, Cirencester, for many years, Dr. Voelcker has now been consulting Chemist to the Royal Agricultural Society of England for more than a quarter of a century; and to some of the results of his investigations I shall have to refer on future occasions.

It was also in 1843, that there was established the Chemico-Agricultural Society of Scotland, which was, I believe, broken up after it had existed between four and five years, because its able Chemist, the late Professor Johnston, failed to find a remedy for the potato disease. Somewhat similar duties, including a good deal of agricultural research, have however since been performed under the auspices of the Highland and Agricultural Society of Scotland, for many years by the late Professor Anderson, and more recently by Dr. Aitken.

In 1845, the Chemico-Agricultural Society of Ulster was established; Professor Hodges was appointed as Chemist, and he continues ably to perform the duties of the office.

As already intimated, agencies of this kind were not so soon brought into operation on the Continent. Nevertheless, the numerous Agricultural Experimental Stations which have been established, not only in Germany, but in most continental States, owe their origin very directly to the writings, the teachings, and the influence of Liebig.

The movement seems to have originated in Saxony, where Stöckhardt had already stimulated interest in the subject by his lectures and his writings. After some correspondence in 1850–51, between the late Dr. Crucius and others on the one side, and the Government on the other, the first so-called 'Agricultural Experimental Station' was established at Möchern, near Leipzig, in 1851–2. In 1877 the twenty-fifth anniversary of the foundation of that Institution was celebrated at Leipzig; when an account, which has since been published, was given of the number of Stations then existing, of the number of Chemists engaged, and of the subjects which had

been investigated. From that statement we learn that at that period the number of Stations was :—

In the various German States	74
In Austria	16
In Italy	10
In Sweden	7
In Denmark	1
In Russia	3
In Belgium	3
In Holland	2
In France	2
In Switzerland	3
In Spain	1
Total	122

Thus, seven years ago there were 122 'Agricultural Stations' on the Continent of Europe, and the number has doubtless by this time considerably increased.

Each of these Stations is under the direction of a Chemist, frequently with one or more assistants. One special duty of most of them is to examine or analyse, and report upon, manures, seeds, or feeding-stuffs, offered for sale to the farmer; and it seems to have been found to be the interest of the dealers in such commodities, to submit their proceedings to a certain degree of supervision by the Chemist of the Station of their District.

But agricultural research has also been a characteristic feature of these institutions. It was stated in the report referred to, that the investigation of soils had been the prominent object at sixteen of them; experiments with manures at twenty-four; vegetable physiology at twenty-eight; animal physiology and feeding experiments at twenty; vine culture and wine making at thirteen; forest culture at nine; and milk production at eleven. Others, according to their locality, have devoted special attention to fruit culture, olive culture, the treatment of moor, bog and

peat land, the production of silk, the manufacture of spirit, and other products.

But few experimental stations having in the main similar objects to those of the Stations on the Continent of Europe, have been established either in our own Country or in America; but in the German Report above cited, Scotland is credited with one, and the United States with one.

There are, however, several Stations in the United States, where agricultural investigation is carried on; and a writer in that Country has recently made an appeal to the Government, to establish Stations with a view to the investigation of each general variety of soil and climate in the United States; to assign a Chemist to each, to institute experiments with the crops most suitable to the locality, to analyse the soil, &c., and to report the results.

The records of the results of the investigations conducted at the large number of experimental stations on the Continent of Europe, are extremely voluminous; and the number of systematic works which have appeared on various branches of the subject in the French and German languages during the last forty years is very great. I will here refer to the several editions of Liebig's first two works already alluded to, his 'Familiar Letters on Chemistry,' his 'Modern Agriculture,' his 'Principles,' and finally his 'Natural Laws of Husbandry,' all of which have appeared in the English language. Reference should also be made to Boussingault's 'Economie Rurale' the first edition of which was published in English in 1845. It has, however, gone through other editions in France; and subsequently, at intervals from 1860 to 1878, Boussingault published a series of six volumes, entitled—'Agronomie, Chimie Agricole et

Physiologie'—and covering a still wider range of subjects, bringing the information on the various points up to date, and going into much detail as to the methods of research, as well as to the results obtained. In these volumes, those who desire it will be able to examine for themselves the evidence upon which many important conclusions have been based.

A few of the works by English authors which have appeared within the same period, it may be well to enumerate. Among them are Johnston's 'Lectures on Agricultural Chemistry and Geology,' first published in 1844; and his 'Experimental Agriculture,' published in 1849. His successor, Dr. Anderson, also published, in 1860, a work entitled—'Elements of Agricultural Chemistry.'

New editions of Johnston's work have since been published by Dr. C. Cameron; the first of these, the tenth of the original work, appearing in 1877.

Perhaps the most compendious record of the results of the Continental investigations up to the time of its publication, which has appeared in our own language, is that by Professor S. W. Johnson, of Yale College, Newhaven, Connecticut, in two volumes, entitled 'How Crops Grow,' and 'How Crops Feed.' The results of the German experiments on the Feeding of Animals have also been summarised by Dr. Armsby, in a volume published in America, and entitled—'Manual of Cattle-Feeding.'

Neither in the works above referred to, nor in the reports of the Continental Experimental Stations, do we find the record of many systematic or long continued field-experiments. We have, however, the example of Boussingault, and the opinions of Sir Humphrey Davy, Liebig, and Daubeny, as to the great importance of such methods of agricultural research.

Davy says:—

'Nothing is more wanting in agriculture than experiments in which all the circumstances are minutely and scientifically detailed. This art will advance with rapidity in proportion as it becomes exact in its methods. As in physical researches, all the causes should be considered; a difference in the results may be produced, even by the fall of a half-inch of rain more or less in the course of a season, or a few degrees of temperature, or even by a slight difference in the subsoil, or in the inclination of the land.'

'Information collected after views of distinct inquiry, would necessarily be fitted for inductive reasoning, and capable of being connected with the general principles of science; and a few histories of the results of truly philosophical experiments in agricultural chemistry would be of more value in enlightening and benefiting the farmer, than the greatest possible accumulation of imperfect trials, conducted merely in the empirical spirit.'

'It is from the higher classes of the community, from the proprietors of land,—those who are fitted by their education, to form enlightened plans, and by their fortunes, to carry such plans into execution; it is from these that the principles of improvement must flow to the labouring classes of the community; and in all classes the benefit is mutual; for the interest of the tenantry must be always likewise the interest of the proprietors of the soil.'

'Discoveries made in the cultivation of the earth are not merely for the time and country in which they are developed, but they may be considered as extending to future ages, and as ultimately tending to benefit the whole human race; as affording subsistence for generations yet to come; as multiplying life; and not

only multiplying life, but likewise providing for its enjoyment.'

Liebig said:—'I shall be happy if I succeed in attracting the attention of men of science to subjects which so well merit to engage their talents and energies. Perfect agriculture is the true foundation of all trade and industry—it is the foundation of the riches of states. But a rational system of agriculture cannot be formed without the application of scientific principles; for such a system must be based on an exact acquaintance with the means of nutrition of vegetables, and with the influence of soils and actions of manure upon them. This knowledge we must seek from chemistry, which teaches the mode of investigating the composition and of studying the characters of the different substances from which plants derive their nourishment.'

'Since the time of the immortal author of the "Agricultural Chemistry" (Davy) no chemist has occupied himself in studying the application of chemical principles to the growth of vegetables, and to organic processes. I have endeavoured to follow the path marked out by Sir Humphrey Davy, who based his conclusions only on that which was capable of inquiry and proof. This is the path of true philosophical inquiry, which promises to lead us to truth —the proper object of our research.'

The importance which Professor Daubeny attached to field-experiments, is evidenced in the facts that, at a very early period of his connection with the study and teaching of the principles of Rural Economy, he instituted the experiments on Rotation, in the Botanic Garden, already referred to; and that subsequently, I believe in 1860, he bequeathed to his successors in the Chair a piece of ground of about one and a

half acre for the purposes of experiments; feeling, as he said in a lecture on the subject, that the objects of the foundation of the Professorship of Rural Economy—'would not be fully attained until the holder of it was enabled, not only to retail the information he might obtain from books, but also to illustrate it by experiment, and to verify, as well as extend the knowledge he might have derived from others through original investigations of his own.'

Briefly described, the subjects which Dr. Daubeny indicated as suitable for such enquiry were—1. To determine what amount of mechanical treatment, and what length of time, would be required to bring an exhausted soil back to fertility without manure. 2. To try whether, if a soil be rich in mineral constituents, ammoniacal manures may not be dispensed with by the use of mechanical operations; since, as he says, Liebig's opinion is, that many plants have the power 'of absorbing from the atmosphere so large an amount of ammonia, as would seem to render them independent of animal manures, and to enable them to derive all their ingredients, except their mineral ones, from the atmosphere.' 3. The causes of the failure of clover. 4. The effects of gypsum applied as manure. 5. To try whether there is any disadvantage in the use of superphosphates from which the fluorine has been dissipated, compared with bones from which it has not. 6. Whether growing plants year after year on the same land from the seed yielded, tends to variation, or to the obliteration of specific characters. 7. Lastly, to determine how far the growth of the fungi which attack different crops may be considered as a cause, or only the effect, of disease.

I may here say that much experimental evidence

is now available with regard to some of these questions, and I shall have to call attention to it in subsequent lectures.

I may add that, very shortly after Dr. Daubeny had bequeathed the piece of ground to which I have referred, I visited it with him, and at the time expressed a fear that it was not very suitable for the objects in view, little thinking that it would fall to my lot to consider the subject more seriously, as I shall soon have to do. In the first place, I pointed out the unlevel character of the plot, and gathered from the history of it given to me, that it was very uneven as to condition. Accordingly, I suggested that, before any experiments on it were undertaken, it should be brought into an even state as far as mechanical operations could accomplish this; and that then some corn-crop should be grown for several years in succession without manure, so as, as far as possible, to obliterate the unevenness of condition arising from previous irregularity in manuring and cropping.

It will doubtless excite surprise when I say that, notwithstanding the importance of the subject, and the high authority on which the prosecution of scientifically conducted field-experiments has been advocated, the conduct of such experiments has never been an important part of the work of the Agricultural Experimental Stations on the continent of Europe, and that it is now almost excluded from their programme.

In 1880, Professor Maercker of Halle, one of the leading Agricultural Chemists of Germany, stated that belief in their value was greatly diminished, and that by some they were declared to be of no value. It is objected that the Chemists of the Agricultural Stations have neither the means nor the technical knowledge necessary for carrying out such experiments

successfully; that neither the amount of land, nor the funds at their disposal, are such as to admit of any safe deductions for application in practical agriculture from the results; and that purely physiological problems can be better investigated in the laboratory, or in the greenhouse. He remarks that, owing to the errors necessarily incident to field-experiments conducted by those not acquainted with practical agriculture, the confidence of the practical farmer in the results has been shaken. Indeed, owing to the difficulties and cost of such enquiries, if conducted in a truly scientific manner, so as to be applicable for the solution of questions of fundamental and general interest, Professor Maercker concludes that the only field-experiments which it is practicable to carry out in Germany, are such as should be conducted by the practical farmer himself, to test the applicability to practice, of results and conclusions otherwise arrived at; and that, to insure that even such experiments are not misleading, similar ones should be conducted on different descriptions of soil, and for several years in succession.

I have already quoted the opinion of Sir Humphrey Davy, that scientifically conducted field-experiments should be undertaken by proprietors of land, who by their education are fitted to form enlightened plans, and by their fortunes are able to carry them into execution; and when I tell you that the Rothamsted field-experiments, independently of all the laboratory investigations connected with them, cost considerably more, and those which have been undertaken by the Duke of Bedford at Woburn for the last seven years, on behalf of the Royal Agricultural Society of England, and which are under the direction of Dr. Voelcker, not much less, than £1000 annually, you

will not be surprised that such field-experiments are not more general.

Prior to the appearance of Liebig's first work, in 1840, Mr., now Sir John Bennet Lawes, commenced experiments with different manuring substances, first with plants in pots, and afterwards in the field, at Rothamsted, into the hereditary possession of which he had entered on his majority in 1834. The results so obtained on a small scale in 1837, 1838, and 1839, were such as to lead to more extensive trials in the field in 1840, 1841, and subsequently.

In 1843, more systematic field-experiments were commenced; and a barn, which had already been applied to laboratory purposes, became almost exclusively devoted to agricultural investigations. These, which are still in progress, have been conducted entirely at the cost of Sir John Lawes, who has further set apart a sum of £100,000, and certain areas of land, for their continuance after his death.

In June 1843, I became associated with Mr. Lawes in the conduct of these investigations; and as it is doubtless my connexion with them (which still continues), to which my election to this Chair is mainly to be attributed, it will not be out of place to give, on this occasion, a brief outline of the scope and plan of the work which has been accomplished, during the more than forty years of its continuance. That I should do so seems the more desirable, since I interpret my appointment as indicating a feeling on the part of the Electors, that the results acquired in this long period of investigation of the scientific principles of agriculture, many of which are known by their publication, must have provided important material for illustration, in the lectures which it will be my

duty to deliver. In fact, whilst I shall not neglect important results and conclusions established by others, the plan which I have in view will nevertheless involve much reliance on the data acquired at Rothamsted.

I may premise that since July 1855, when a new laboratory, built by public subscription of agriculturists, was presented to Mr. Lawes, the old barn laboratory has been abandoned. At the present time, the Rothamsted staff consists of two, and sometimes three chemists; several general assistants in different departments; occasionally a botanical assistant; three, and sometimes four, computors and record keepers; also a laboratory man, and several boys.

The general scope and plan of the field-experiments has been—to grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farmyard manure, and with a great variety of chemical manures; the same description of manure being, as a rule, applied year after year on the same plot. Experiments, with different manures on the mixed herbage of permanent grass-land, on the effects of fallow, and on an actual course of rotation, without manure, and with different manures, have likewise been made.

Field-experiments have thus been conducted for the periods, and over the areas, indicated in the table on the following page.

Samples of all the experimental crops are brought to the laboratory. Weighed portions of each are partially dried and preserved for future reference, or analysis. Duplicate weighed portions of each are dried at 100°C, the dry matter determined, and then burnt to ash. The quantities of ash are determined

Rothamsted Field Experiments.

Crops.	Duration.	Area.	Plots.
	Years.	*Acres.*	
Wheat (various manures) . . .	41	13	37
Wheat, alternated with Fallow .	33	1 .	2
Wheat (varieties)	15	4–8	about 20
Barley (various manures) . . .	33	4¼	29
Oats (various manures)	10[1]	¾	6
Beans (various manures) . . .	32[2]	1¼	10
Beans (various manures) . . .	27[3]	1	5
Beans, alternated with Wheat . .	28[4]	1	10
Clover (various manures) . . .	30[5]	3	18
Various Leguminous Plants . .	7	3	17
Turnips (various manures) . . .	28[6]	8	40
Sugar Beet (various manures) .	5	8	41
Mangel-Wurzel (various manures) .	9	8	41
Total Root Crops . .	42		
Potatoes (various manures) . . .	9	2	10
Rotation (various manures) . .	37	2½	12
Permanent Grass (various manures)	29	7	22

and recorded; the ashes themselves being preserved for reference, or analysis.

In a large proportion of the samples the total nitrogen is determined; and in some the amount existing as albuminoids, amides, and nitric acid.

In selected cases, illustrating the influence of season, manures, exhaustion, &c., complete ash-analyses have been made, numbering in all more than 700.

Also in selected cases, illustrating the influence of season and manuring, quantities of the experi-

[1] Including 1 year Fallow.

[2] Including 1 year Wheat, and 5 years Fallow.

[3] Including 4 years Fallow.

[4] Including 2 years Fallow.

[5] Clover, 12 times sown, 8 yielding crops, but 4 of these very small, 1 year Wheat, 5 years Barley, 12 years Fallow.

[6] Including Barley without manure 3 years (11th, 12th, and 13th seasons).

mentally grown wheat-grain have been sent to the mill, and the proportion and composition of the different mill-products has been determined.

In the sugar-beet, mangel-wurzel, and potatoes, the sugar in the juice has in many cases been determined by polariscope, and frequently by copper also.

In the case of the experiments on the mixed herbage of permanent grass-land, besides the samples taken for the determination of the chemical composition (dry matter, ash, nitrogen, woody fibre, fatty matter, and composition of ash), carefully averaged samples have frequently been taken for the determination of the botanical composition. In this way, on four occasions, at intervals of five years —viz., in 1862, 1867, 1872, and 1877—a sample of the produce of each plot was taken, and submitted to careful botanical separation; and the percentage, by weight, of each species in the mixed herbage determined. Partial separations, in the case of samples from selected plots (frequently of both first and second crops), have also been made in other years.

Samples of the soils of most of the experimental plots have been taken from time to time, generally to the depth of 9, 18, and 27 inches; sometimes to twice, and sometimes even to four times this depth. In this way more than 1000 samples have been taken, submitted to partial mechanical separation, and portions of the fine soil (that is, excluding stones) have been carefully prepared and preserved for analysis. In a large proportion of the samples the loss on drying at different temperatures, and at ignition, has been determined. In most, the nitrogen determinable by burning with soda-lime has been estimated. In many the carbon, and in some the

nitrogen as nitric acid, and the chlorine, have been determined. Some experiments have also been made on the comparative absorptive capacity (for water and ammonia) of different soils and subsoils. The systematic investigation of the amount, and the condition, of the nitrogen, and of some of the more important mineral constituents, of the soils of the different plots, and from different depths, is now in progress, or contemplated.

Almost from the commencement of the experiments the rainfall has been measured—for more than thirty years in a gauge of one-thousandth of an acre area, as well as in an ordinary small funnel-gauge of 5 inches diameter. An 8-inch 'Board of Trade' copper-gauge is also now in use, commencing January 1, 1881. From time to time, the nitrogen as ammonia (and sometimes as nitric acid), has been determined in the rain waters. The chlorine has also been determined in many samples.

Three 'drain gauges,' also of one-thousandth of an acre each, for the determination of the quantity and composition of the water percolating, respectively through 20 inches, 40 inches, and 60 inches depth of soil (with its subsoil in natural state of consolidation), have also been constructed. Each of the differently manured plots of the permanent experimental wheat-field having a separate pipe-drain, the drainage-waters have been, and are frequently, collected and analysed.

The nitrogen existing as nitric acid, sometimes that in other forms, and also some other constituents, are, and for some time past have been, determined periodically, in both the rain and the various drainage waters.

For several years in succession, experiments were

made to determine the amount of water given off by plants during their growth. In this way various plants, including representatives of the gramineous, the leguminous, and other families, have been experimented upon. Similar experiments have also been made with various evergreen and deciduous trees.

Having regard to the difference in the character and amount of the constituents assimilated by plants of different botanical relationships, under equal external conditions, or by the same description of plants, under varying conditions, observations have been made on the character and range of the roots of different plants, and on their relative development of stem, leaf, &c. In the case of various crops, but more especially with wheat and beans, samples have been taken at different stages of growth, and the composition determined, in more or less detail, sometimes of the entire plant, and sometimes of the separated parts. In a few cases, the amounts of dry matter, ash, nitrogen, &c., in the above-ground growth of a given area, at different stages of development, have been determined. The amounts of stubble of different crops have also occasionally been estimated.

Experiments were made for several years in succession to determine whether plants assimilated free or uncombined nitrogen, and also various collateral points. Plants of the gramineous, the leguminous, and of other families, were operated upon. The late Dr. Pugh took a prominent part in this enquiry.

Obviously, an investigation of the scientific principles of Agriculture would be incomplete if it were

not extended to the question of the feeding of the animals of the farm. Accordingly, experiments with such animals were commenced early in 1847, and have been continued at intervals up to the present time.

The following points have been investigated :—

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal, within a given time.

2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.

3. The proportion, and relative development, of the different organs or parts of different animals.

4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.

5. The composition of the solid and liquid excreta (the manure), in relation to that of the food consumed.

6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat—and —manure-making machine.

Several hundred animals—oxen, sheep, and pigs—have been submitted to experiment.

The amount, and the relative development, of the different organs and parts, were determined in two calves, two heifers, fourteen bullocks, one lamb, 249 sheep, and 59 pigs.

The percentages of water, mineral matter, fat, and nitrogenous substance, were determined in certain separated parts, and in the entire bodies, of ten animals—namely, one calf, two oxen, one lamb, four

sheep, and two pigs. Complete analyses of the ashes, respectively, of the entire carcases, of the mixed internal and other 'offal' parts, and of the entire bodies, of each of these ten animals have also been made.

From the data provided, as just described, as to the chemical composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated.

To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs, have been experimented upon.

The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly, but only by difference; that is, by calculation, founded on the amounts of dry matter, ash, nitrogen, &c., in the food, and in the (increase) fæces, and urine.

Independently of the points of enquiry here enumerated, the results obtained have supplied data for the consideration of the following questions:—

1. The characteristic demands of the animal body, for nitrogenous or non-nitrogenous constituents of food, in the exercise of muscular power.

2. The sources in the food of the fat produced in the animal body.

3. The comparative characters of animal and vegetable food in human dietaries.

Supplementary investigations have also been made; for example—on the application of town-sewage to different crops, including experiments on the feeding qualities of the produce grown; the amount of increase yielded by oxen, and the amount and com-

position of the milk yielded by cows, being determined.

The chemistry of the malting process, the loss of food constituents during its progress, and the comparative feeding value of barley and malt, have also been investigated.

Many of the results of the investigations above enumerated have already been published, but a large proportion as yet remains unpublished.

As already intimated, I propose to rely largely on the data supplied in the more than forty years of investigation at Rothamsted, in the field, the feeding-shed, and the laboratory, in the lectures which it will be my duty to give in this University, in elucidation of the scientific principles of agriculture.

In the first place, however, to give logical sequence to what will follow, I shall devote a few lectures to the question of the sources of the constituents of the plants and animals which are the products of the art of agriculture. Obviously, the soil, and the atmosphere, are these sources. The subject of the origin, the general characters, and the composition, of soils, is a very wide one; and many lectures might be devoted to its discussion. But it is foreign to my plan so to discuss it; as to do so would seriously trench upon the time which should be devoted to the consideration of other branches of our enquiry.

I shall next consider the effects of manures, exhaustion, and variations of season, on the amounts of produce, and on the composition of the produce, of different crops, the effects of fallow, and the benefits arising from a rotation of crops.

Subsequently, I propose to take up the subject of the feeding of animals, for the production of meat,

milk, and manure, and for the exercise of force—that is, for their labour. Also, if opportunity should occur, to treat of the question of the application of town-sewage to the land.

Finally, I should observe that, throughout the illustrations which I shall bring before you, it will be my endeavour to keep in view the bearing of the data with which I shall have to deal, on the important question of compensation for unexhausted improvements, so much in discussion at the present time.

The first experiments on crops to which I shall direct attention, will be those on the cereals; for, although bad seasons, and foreign competition, have of late tended to lessen the relative importance of these products to the British farmer, the experimental evidence obtained, both in the field and in the laboratory, is more complete in regard to them than to any other crops; and the discussion of the results, will afford the opportunity of considering important questions of wider interest to agriculture, than those exclusively relating to the production of the cereal crops themselves.

Printed at the University Press, Oxford

By HORACE HART, *Printer to the University*

ON THE COMPOSITION

OF THE

ASH OF WHEAT-GRAIN, AND WHEAT-STRAW,

GROWN AT ROTHAMSTED, IN DIFFERENT SEASONS, AND BY DIFFERENT MANURES.

BY

SIR J. B. LAWES, BART., LL.D., F.R.S., F.C.S., and
J. H. GILBERT, PH.D., LL.D., F.R.S., V.P.C.S.

From the Journal of the Chemical Society, Vol. XLV, *August*, 1884.

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1884.

LONDON:
HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE.

On the Composition of the Ash of Wheat-Grain, and Wheat-Straw, grown at Rothamsted, in different Seasons, and by different Manures.

By Sir J. B. Lawes, Bart., LL.D., F.R.S., F.C.S., and J. H. Gilbert, Ph.D., LL.D., F.R.S., V.P.C.S.

CONTENTS.

	PAGE
Introduction	3
First Series of Analyses	5
Second Series of Analyses	28
Third Series of Analyses	48
Summary and Conclusions	68
Appendix-Tables	80

In the *Journal of the Chemical Society* for 1857, we published a paper entitled:—"On some Points in the Composition of Wheat-Grain, its Products in the Mill, and Bread." In that paper the results of 23 wheat-grain ash-analyses were embodied. The present paper relates to the analyses of 92 wheat-grain and 92 wheat-straw ashes, and including 69 duplicates, the number of complete ash-analyses involved is 253. Every ash is of produce of known history of growth, as to soil, season, and manuring. Thus, there is a series for 16 consecutive seasons, under three very characteristically different conditions as to manuring. There is a series representing nine different conditions as to manuring, each in two unfavourable, and in two favourable seasons for the crop. Lastly, there is a series representing the proportionally mixed produce for the 10 years, 1852–1861, and again for the succeeding 10 years, 1862–1871, for 10 differently manured plots in each case.

The results are thus calculated to illustrate the influence of fluctuations of season from year to year under known, but very different conditions as to manuring; the influence of characteristic seasons under a great variety of manuring conditions; and the influence of continuous supply or exhaustion of certain constituents.

Most of the results have long been waiting for an opportunity of full discussion; but as such opportunity seems still remote, it is proposed now to submit them, arranged in such form as will be convenient for reference; and to accompany the record with only so much of explanation and discussion, as will suffice to indicate the most important conclusions, and usefully to direct the further study of the results.

In explanation of the history of the specimens from which the ashes have been obtained, it should be stated that they have all been grown in the experimental field at Rothamsted, which has now yielded wheat for 40 years in succession, 1844 to 1883 inclusive, respectively without manure, with farmyard manure, and with a great variety of artificial manures; the same manure being, as a rule, applied year after year, to the same plot. The descriptions of wheat grown have been as follows:—1844–1848, Old Red Lammas; 1849–1852, Red Cluster; 1853–1881, Red Rostock; 1882 and since, Club Wheat (red); all of which are well acclimatised, and, with the exception of the first, not very dissimilar varieties.

In the body of the paper, the results of each of the three series of analyses are arranged in Summary Tables, in convenient forms for illustration, and they are given more fully and in more systematic form in the Appendix-Tables I—XV (p. 80, *et seq.*), as under:—

1. The analytical results, excluding sand and charcoal, calculated to 100.*
2. Each constituent calculated per 1000 dry matter of produce.
3. Each constituent calculated per acre, actual produce.

The method of preparing the ashes is as follows:—The substance, generally 20 ounces = 567 grams of wheat-grain, and 12·5 ounces = 354 grams of wheat-straw, is burnt on platinum sheets turned up at the sides and at the back, thus forming dishes about 12 inches long and 4½ inches wide. These are heated in cast-iron muffles, 18 inches long, 3½ inches high, and 5 inches wide at the bottom. Each muffle, which has a flange at the fore part, fits exactly into an orifice in a cast-iron furnace front; and a cast-iron pipe of 1½ inch bore is fixed into the back of the muffle, and passes through the cast-iron furnace back. The muffle rests on a fire brick, so that the fuel is in direct contact only with its sides and top, chiefly the latter, thus lessening bottom heat and, as far as possible, preventing fusion. By this arrangement, the access of dust from the fire is entirely avoided; the ash is burnt by surface, not by bottom heat; the access of air is free, and the incineration is accomplished at a low temperature. Of the 253 ash analyses, nine have been made by Mr. F. A. Manning, and six by Mr. R. Warington. The whole of the remainder (238) have been executed by Mr. R. Richter; the earlier ones in the Rothamsted Laboratory, and the later in his own laboratory at Charlottenburg (Berlin). Mr. Richter has in fact executed about 700 complete analyses of the ashes of various products, animal and vegetable, of known history, prepared at Rothamsted. He

* Where duplicate analyses have been made the mean results are adopted.

has also conducted numerous investigations of method, with the view to testing the limits of accuracy of previous work, and to attain greater accuracy in future; and in the course of these inquiries he has analysed mixtures of precipitates obtained in precisely the same way in series of analyses, to determine their degree of purity, and so on. It is not intended on the present occasion to go into these matters of detail, which of themselves would supply sufficient material for an independent paper.* It will be seen that Mr. Richter's experience has thus been very great; and independently of the confidence in the results which our knowledge of his competency and conscientiousness inspires, their consistency with the history of the specimens, which will be amply illustrated further on, can leave no doubt of their trustworthiness and value. On this point it should be stated in justice to Mr. Richter that all the ashes, duplicates included, have been supplied to him under consecutive numbers, without any indication as to the history of the specimens.

First Series of Analyses.

In our former paper, above referred to, analyses of the grain-ash only, from the produce of eight of the differently manured plots in the first season 1844, of seven in 1845, and of six in 1846, were given; and in two cases duplicate analyses were made, making in all 23. At that time, the plan of applying the same manure to the same plot each year had not been fully adopted; nor were the straw-ashes of those early years analysed. The series now to be considered includes the analyses of both grain-ash and straw-ash, from three of the differently manured plots, in each of 16 consecutive seasons, commencing with the fifth, 1848, and ending with the twentieth, 1863. Two of the three plots have, respectively, been under the same treatment from the first year,

* It may here be remarked, however, that the first and second series of analyses were made more than 15 years ago, since which time there has been much discussion of the details of the magnesium method for the determination of phosphoric acid, by which process nearly the whole of those results were obtained. It is now generally admitted that the conditions of experiment then recommended by the highest authorities are liable to give high results; and Mr. Richter's subsequent investigations of method referred to above, lead him to the same conclusion. The actual results obtained are, however, in all cases adopted; nor would any of the conclusions drawn be affected, if correction had been made in accordance with the indications of the subsequent examinations of method. It should be further stated that indications of the presence of manganese in probably determinable quantity having been observed in some wheat grain-ashes, some quantitative estimations were made, and the amounts found corresponded to a mean of 0·26 per cent. Mn_3O_4. The indications in the case of straw-ashes have not been such as to lead to quantitative determinations being made; but it may be supposed that the amount of manganese in them would at any rate not be less than in the grain-ashes.

1844, and the third has been substantially so from the second year, 1845, as explained more in detail below.

The three plots are:—

Plot 2. Farmyard manure, 14 tons per acre, every year from the commencement.

Plot 3. Unmanured, every year from the commencement.

Plot 10*a*. First year (1844), a mineral manure consisting of superphosphate of lime, and a crude silicate of potash; second year, 168 lbs. sulphate, and 168 lbs. muriate of ammonia of commerce, per acre; third year, 224 lbs. sulphate of ammonia; fourth and fifth years, 150 lbs. sulphate and 150 lbs. muriate; sixth and each succeeding year, 200 lbs. sulphate and 200 lbs. muriate of ammonia, per acre per annum.

The conditions of growth, so far as the supply of constituents by manure is concerned, were therefore very widely different in the three cases. Thus, the produce of Plot 2, with farmyard manure, was grown under the influence of an excessive supply both of nitrogen and of mineral, or ash-constituents; that of Plot 3, unmanured, under conditions of exhaustion of both nitrogen and ash-constituents; and that of Plot 10*a* (receiving ammonium-salts alone), with an excess of supplied nitrogen, but with great relative deficiency of ash-constituents. If, therefore, the composition of the ash of the produce is directly affected by the available supply of ash-constituents within the soil, we should expect very marked differences in the composition of the ash in the three cases.

The Appendix-Tables I, II, and III (pp. 80–85), give the percentage composition of the pure grain-ash, and the pure straw-ash, for each of the 16 consecutive years: I, for the farmyard manure plot; II, for the unmanured plot; and III, for the plot with ammonium-salts alone. By the term "pure" ash is meant the ash excluding sand and charcoal. Referring to these Appendix-Tables for the full details, the results will be discussed chiefly by the aid of a series of summary tables.

The following summary Table, I, brings prominently to view some important facts, and indicates some important conclusions. There is there given for each of the three differently manured plots, the highest, the lowest, and the mean percentages of potash and phosphoric acid, in the grain-ash, and in the straw-ash, in the 16 consecutive years. There is thus shown the extreme range of variation in the composition of the ash in some important particulars, with the same manure in very various seasons, and also the range with the different manures. It may be observed that the two constituents selected for illustration together contribute between 80 and 85 per cent. of wheat grain-ash.

TABLE I.

Highest, Lowest, and Mean Percentages of Potash and Phosphoric Acid *in the Pure Ash*, in 16 Consecutive Seasons.

Plots.	Manures.	Per cent. in grain-ash.			Per cent. in straw-ash.		
		Highest.	Lowest.	Mean 16 years.	Highest.	Lowest.	Mean 16 years.
		Potash.					
2	Farmyard manure	35·5	27·2	31·6	25·6	12·9	18·3
3	Unmanured	35·5	29·7	33·0	20·7	10·5	14·6
10a	Ammonium-salts alone	35·9	28·1	33·4	23·4	10·5	16·5
		Phosphoric Acid.					
2	Farmyard manure	54·7	47·1	51·7	6·21	2·98	3·79
3	Unmanured	52·6	45·6	49·7	5·96	2·98	3·79
10a	Ammonium-salts alone	52·9	43·4	47·3	4·34	1·73	3·09

A glance at the table shows that in both grain-ash and straw-ash there is, in the case of both constituents, a much wider range of variation in their percentage in the ash with the same manure in different seasons, than there is in the mean percentage under each of the three very characteristically different conditions as to manuring.

Thus, the percentages of potash in the grain-ashes in the 16 seasons range—with farmyard manure, from 35·5 to 27·2; without manure, from 35·5 to 29·7; and with ammonium-salts alone, from 35·9 to 28·1. But the mean percentage over the 16 years only ranges between 31·6 with farmyard manure, 33·0 without manure, and 33·4 with ammonium-salts alone. The amount of potash in the straw-ashes shows a still greater range in different seasons with the same manure, and comparatively small differences in the mean percentages under the influence of the different manures. Thus, the variation in the percentage of potash in the straw-ashes according to season is—with farmyard manure, from 25·6 to 12·9; without manure, from 20·7 to 10·5; and with ammonium-salts alone, from 23·4 to 10·5; whereas the difference between the mean percentages over the 16 years is, under the three different conditions as to manuring, very much less, the mean amounts being with farmyard manure 18·3, without manure 14·6, and with the ammonium-salts 16·5.

The facts relating to phosphoric acid are equally striking. Thus, its percentage in the grain-ash ranges, according to season—with farmyard manure, from 54·7 to 47·1; without manure, from 52·6 to 45·6; and with ammonium-salts, from 52·9 to 43·4; but the difference between the mean percentages under each condition of manuring over the 16 years, is only as follows:—with farmyard manure 51·7, without manure 49·7, and with ammonium-salts 47·3. Again, the variation in the percentage of phosphoric acid in the straw-ashes is, according to season—with farmyard manure, from 6·21 to 2·98; without manure, from 5·96 to 2·98; and with ammonium-salts alone, from 4·34 to 1·73; whereas the mean percentage over the 16 years is—with farmyard manure 3·79, without manure 3·79, or exactly the same as with farmyard manure, and with ammonium-salts alone 3·09.

With both potash and phosphoric acid, therefore, there is very great difference in the percentage in the ash of both grain and straw, according to season, and very much less difference in the mean percentage according to manure. With few exceptions, a similar result is observed with other constituents.

What is the significance of these facts? In the first place it is that the character of development of a crop left to ripen, depends very much more upon season than upon manuring. Indeed, if one crop (of wheat for example) grows side by side with another of exactly the same description, but yielding under the influence of manure twice the amount of produce, and both under such conditions of season that each fully and normally ripens, the composition of the final product, the seed, will be very nearly identical in the two cases. In other words, there is scarcely any difference in the composition of the truly and normally ripened seed. But, as variations of season affect the character of development, and the conditions of maturation, there may obviously be, with these, very wide differences in the composition of the product. The wide range in the composition of the ash of the grain, which the table shows according to season, represents in fact a corresponding deviation from the normal development.

It should be noted that the highest and the lowest percentages of both potash and phosphoric acid in the grain-ashes, as given in the tables, are in the produce of very unfavourable seasons, thus further showing how varied are the characters of development dependent on the varying external conditions of season. In the case of the straw ashes, the highest percentages of potash are not, but the lowest are, in the produce of unfavourable seasons; and the highest percentages of phosphoric acid are, and the lowest are not, in unfavourable seasons. The differences between the grain-ashes and the straw-ashes in these respects will be better understood as we proceed. But it may be remarked in passing that the results are connected with the

facts that unfavourable seed-forming and ripening conditions may supervene on conditions of high or of low luxuriance, that is, of great or limited activity of accumulation of constituents by the plant; or, on the other hand, favourable seed-forming and ripening conditions may supervene on very various conditions as to previous accumulation.

Table II shows the variation according to season and manure, not in the percentage composition of the ash, but in the amount of potash and phosphoric acid *per* 1000 *dry substance* of the grain and the straw respectively. This mode of representation obviously brings more prominently to view the variations in the proportion of the two ash-constituents to the organic substance produced.

TABLE II.

Highest, Lowest, and Mean Amounts of Potash and Phosphoric Acid *per* 1000 *Dry Substance.*

Plots.	Manures.	Per 1000 dry grain.			Per 1000 dry straw.		
		Highest.	Lowest.	Mean 16 years.	Highest.	Lowest.	Mean 16 years.
				Potash.			
2	Farmyard manure	7·79	5·38	6·35	18·37	9·06	11·91
3	Unmanured	8·38	6·01	6·62	14·16	6·96	9·30
10a	Ammonium-salts alone	7·38	5·15	6·02	13·24	5 69	8·71
				Phosphoric Acid.			
2	Farmyard manure	11·10	9·65	10·44	4·12	1·49	2·45
3	Unmanured	10·75	8·98	10·03	3·74	1·65	2·42
10a	Ammonium-salts alone	10·03	7·18	8·54	3·47	0·93	1·63

It is here seen that the proportion of both potash and phosphoric acid to the organic substance, even of the grain, which, if normally ripened, is assumed to be a comparatively uniform product, varies very considerably according to season; whilst, at any rate as between the grain grown by farmyard manure, and that grown without manure, the mean proportion over the 16 years differs but little. The grain grown under the influence of the ammonium-salts alone, that is, as will afterwards be further illustrated, under conditions of

very abnormal mineral exhaustion, shows not only a wide range in the proportions of both potash and phosphoric acid, especially the latter, according to season, but much lower mean amounts than either with farmyard manure or without manure. In the straw, the range of variation is seen to be much wider still according to season; and it is considerable also according to manure. In the case of straw, we should not expect the amounts of mineral constituents finally retained to bear so uniform a proportion to the organic substances as in that of the grain. Besides the amounts of mineral constituents that may be essential to the organic formations of the straw itself, there will be a variable quantity accumulated in the plant, and not finally appropriated by the seed.

The next point to consider is—what is the connection between high or low amount of the different ash-constituents and the quality of the produce? Table III (pp. 12–13) is arranged to illustrate this. The question here arises, what is the proper measure of quality of produce? So far as the grain is concerned, the weight per bushel, although by no means a perfect measure, is at any rate the best single character recognised in practice. High and equal weight, or low and equal weight, may, however, respectively be accompanied by different characters in other respects. But grain of high weight per bushel would be classed by the farmer and miller as of good, and grain of low weight, of bad quality. It is to be regretted that the average weight of a given number of seeds, or the number of seeds contributing to a given weight, has not been determined; but, in defect of such data, we adopt weight per bushel as the best conventional measure of quality at our command.

The produce of the 16 years on each of the three plots is arranged in the Table (III), in the order of highest weight per bushel; and other characters which have also to be taken into account, are given side by side. Thus, in the succeeding columns of the table are given, the quantity of grain to 100 straw, the quantity of produce (grain, straw, and total) per acre in lbs.; and the percentages of pure ash and of nitrogen in the dry matter of the grain. Lastly, in the columns to the right of those showing these general characters, are recorded the percentages of some selected constituents in the grain-ash (pure), and the proportion of the same constituents in 1000 dry substance of the grain. The upper division of the Table gives the results for the produce of the farmyard manure plot, the middle division for the unmanured plot, and the lower division for the plot with ammonium-salts alone.

The Table (III), shows that, under each of the three conditions as to manuring, the eight seasons of higher weight per bushel also yield on the average a higher proportion of grain to straw,

and higher amounts of produce, than the eight of lower weight per bushel. But although there is with high average weight per bushel of the grain, this general tendency to higher characters of produce in other respects, the coincidence of these characters is very far from being borne out in detail.

Thus, with farmyard manure, the season giving the highest weight per bushel (1849) gives considerably less than the average amount per acre of both grain and straw, especially the latter, and although high, not the highest proportion of grain to straw. Again, of the three years of highest amount of total produce, 1863, 1854, and 1859, the two former give high weight per bushel of grain, but 1859 a very low weight per bushel. The fact is, as already alluded to, high character of grain, as indicated by high weight per bushel, which depends on favourable ripening and harvest weather, may supervene on conditions either of restricted growth, or of high luxuriance—that is, high vegetative activity and great accumulation.

Without manure, the year of highest weight per bushel (1863) is one of about average amount of produce on that plot, and of high, but not the highest proportion of grain to straw.

With ammonium-salts alone, the year of highest weight per bushel (1863) is also the year of highest total produce, and of nearly the highest proportion of grain to straw with that manure.

Again, with each condition as to manuring, there is with high quality of grain, as shown by high weight per bushel, a general and marked, but not uniform tendency to low percentage of total mineral constituents (ash), and also low percentage of nitrogen, in the dry substance of the grain. That is to say, the higher quality of the grain is connected with a greater accumulation of the non-nitrogenous matters primarily derived from the atmosphere, in proportion to the amounts of the soil-derived ash-constituents and the nitrogen, which have been stored up. In fact, in comparable cases, high quality of grain means high proportion of carbohydrates (starch), and coincidently low proportion of nitrogenous substances.

As there is lower percentage of total ash with higher quality of grain, there is necessarily a lower proportion of individual mineral constituents in the dry substance. Accordingly, with each of the three conditions as to manuring there is—taking the average of the eight years of highest weight per bushel—almost without exception a lower proportion of each of the individual mineral constituents in the dry substance of the grain than on the average of the eight years of lower weight per bushel. This is more or less the case with lime, magnesia, potash (soda), phosphoric acid (sulphuric acid), and silica. The actual amount of silica is in all cases small; but the difference in the amount is greater than that of any of the

TABLE III.

General Characters of the Produce; *percentage* of Selected Constituents *in the* *of Grain.* Harvests in order of

	Harvests.	Weight per bushel, lbs.	Grain to 100 straw.	Produce, per acre, lbs.			Per cent. in dry matter.		Per cent. in grain ash (pure).		
				Grain.	Straw.	Total.	Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.
Plot 2.—Farmyard Manure.	1849.....	63·8	68·3	2068	3029	5097	1·58	1·93	2·52	10·6	33·1
	1851.....	63·6	66·2	2049	3094	5143	1·57	1·93	2·88	11·1	32·4
	1863.....	63·1	67·5	2886	4279	7165	1·52	1·85	2·34	11·4	31·5
	1858.....	62·6	65·5	2512	3837	6349	1·91	2·04	2·61	11·2	31·9
	1854.....	62·5	60·1	2675	4450	7125	1·70	1·98	2·46	11·3	32·0
	1855.....	62·0	58·2	2237	3845	6082	2·19	2·08	2·49	11·0	30·9
	1850.....	61·9	57·3	1861	3245	5106	1·86	2·04	2·80	11·1	31·4
	1862.....	61·0	58·3	2447	4195	6642	1·57	1·99	2·51	11·1	32·0
	Mean ...	62·6	62·5	2342	3747	6089	1·73	1·98	2·58	11·1	31·9
	1861.....	60·5	71·0	2202	3101	5303	1·95	2·15	2·52	10·3	33·1
	1857.....	60·4	77·9	2587	3323	5910	1·97	1·94	2·88	12·0	29·8
	1856.....	58·6	52·8	2277	4317	6594	1·89	1·98	2·53	11·7	29·3
	1848.....	58·2	56·0	1705	3041	4746	1·89	2·03	2·41	10·8	30·2
	1852.....	58·2	49·6	1716	3457	5173	2·02	1·98	2·79	12·8	27·2
	1859.....	56·5	47·1	2263	4810	7073	2·09	2·11	2·37	11·2	31·2
	1860.....	55·5	54·2	1864	3440	5304	2·00	2·15	2·78	10·1	33·8
	1853.....	51·1	33·2	1120	3372	4492	1·76	2·20	2·60	10·2	35·5
	Mean ...	57·4	54·5	1967	3607	5574	1·96	2·06	2·61	11·1	31·3
Plot 3.— Unmanured.	1863.....	62·7	70·4	1127	1600	2727	1·65	1·95	2·66	10·9	32·3
	1849.....	61·4	76·1	1229	1614	2843	1·73	1·88	3·15	9·7	35·3
	1851.....	61·1	66·6	1083	1627	2710	1·67	1·94	2·98	10·2	34·7
	1854.....	60·6	63·6	1359	2137	3496	1·92	1·95	2·67	10·4	34·2
	1850.....	60·6	58·2	1002	1719	2721	1·83	2·02	2·98	9·9	33·0
	1858.....	60·4	68·3	1141	1670	2811	1·86	2·02	2·76	10·5	32·7
	1856.....	59·2	60·0	1072	1787	2859	2·14	2·02	2·64	9·9	33·9
	1857.....	58·3	78·3	1236	1577	2813	1·91	1·92	3·39	10·8	32·0
	Mean ...	60·5	67·4	1156	1716	2872	1·84	1·96	2·90	10·3	33·5
	1862.....	57·8	58·2	996	1713	2709	1·76	2·03	2·54	10·2	32·3
	1861.....	57·4	58·7	736	1254	1990	2·04	2·19	2·68	9·6	34·4
	1848.....	57·3	55·6	952	1712	2664	2·17	2·00	2·87	10·4	31·2
	1852.....	56·6	53·9	860	1597	2457	2·08	2·03	2·87	11·7	29·7
	1856.....	54·3	57·3	892	1558	2450	1·91	2·04	2·55	10·8	30·6
	1860.....	52·6	50·6	738	1459	2197	1·92	2·16	2·71	9·1	33·6
	1859.....	52·5	48·3	1051	2175	3226	1·96	2·08	2·75	11·0	31·9
	1853.....	45·9	25·4	359	1413	1772	2·09	2·36	3·09	10·3	35·5
	Mean ...	54·3	51·1	823	1610	2433	1·98	2·08	2·76	10·4	32·
Plot 10a.—Ammonium-salts alone.	1863.....	62·6	74·3	2587	3481	6068	1·70	1·56	3·85	11·2	34·4
	1849.....	62·3	75·1	2141	2851	4992	1·95	1·67	3·46	10·3	35·6
	1851.....	61·9	64·0	1966	3070	5036	2·15	1·81	3·51	10·7	32·6
	1854.....	60·5	61·5	2211	3597	5808	2·30	1·72	3·36	10·2	35·8
	1850.....	60·2	55·7	1721	3089	4810	2·13	1·86	3·63	10·7	33·2
	1858.....	59·6	67·6	1439	2130	3569	2·23	1·90	4·05	10·5	33·5
	1848	58·1	56·3	1334	2367	3701	2·42	1·95	3·22	10·8	30·6
	1857.....	58·0	75·9	1816	2392	4208	2·08	1·63	4·38	11·7	31·6
	Mean ...	60·4	66·2	1902	2872	4774	2·09	1·74	3·68	10·8	33·4
	1855.....	57·1	51·2	1285	2512	3797	2·40	1·91	3·57	10·4	34·7
	1862.....	56·5	56·2	1457	2593	4050	1·89	1·84	3·54	10·7	34·2
	1852.....	55·9	47·3	1320	2787	4107	2·48	1·83	3·51	12·7	28·1
	1856.....	55·6	53·4	1505	2818	4323	2·23	1·85	3·61	11·4	31·9
	1861.....	55·0	44·2	854	1930	2784	2·08	2·00	3·47	10·0	35·5
	1859.....	51·5	44·2	1207	2730	3937	2·30	1·86	3·64	11·2	32·7
	1860.....	49·5	40·9	905	2213	3118	2·24	2·12	3·41	9·1	34·8
	1853.....	48·6	31·3	642	2049	2691	2·43	1·98	3·75	9·3	35·9
	Mean ...	53·7	46·7	1147	2454	3601	2·25	1·91	3·56	10·6	33·5

TABLE III.

Grain-Ash (pure), and amount of the Ash-Constituents *per* 1000 *Dry Matter* Highest Weight per bushel of Grain.

Per cent. in grain ash (pure).			Per 1000 of dry matter of grain.						Harvests.
Phosphoric acid.	Sulphuric acid.	Silica.	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Silica.	
50·3	1·51	0·53	0·49	2·03	6·37	9·7	0·29	0·10	1849
50·7	0·92	0·66	0·55	2·15	6·25	9·8	0·18	0·13	1851
52·0	0·93	0·65	0·43	2·12	5·85	9·7	0·17	0·12	1863
51·9	0·75	0·49	0·53	2·28	6·52	10·6	0·15	0·10	1858
52·2	0·47	0·50	0·49	2·24	6·34	10·4	0·09	0·10	1854
53·3	0·03	0·70	0·52	2·29	6·43	11·1	0·01	0·14	1855
50·5	1·42	0·92	0·57	2·27	6·41	10·3	0·29	0·19	1850
51·6	0·51	0·83	0·50	2·22	6·37	10·3	0·10	0·16	1862
51·6	0·83	0·66	0·51	2·20	6·30	10·2	0·16	0·13	Mean
51·4	1·01	0·50	0·54	2·21	7·12	11·1	0·22	0·11	1861
52·5	0·46	0·49	0·56	2·32	5·79	10·2	0·09	0·10	1857
54·2	0·23	0·75	0·50	2·32	5·80	10·7	0·05	0·15	1856
52·7	0·56	1·56	0·49	2·19	6·11	10·7	0·11	0·32	1848
54·7	0·14	0·99	0·55	2·53	5·38	10·8	0·03	0·20	1852
52·6	0·51	0·80	0·50	2·36	6·58	11·1	0·11	0·17	1859
49·4	0·87	1·28	0·60	2·18	7·27	10·7	0·19	0·27	1860
47·1	2·35	0·93	0·57	2·23	7·79	10·3	0·52	0·20	1853
51·8	0·76	0·91	0·54	2·29	6·40	10·7	0·14	0·18	Mean
51·6	0·67	0·59	0·52	2·12	6·28	10·0	0·13	0·12	1863
47·7	1·83	0·74	0·59	1·83	6·65	9·0	0·34	0·14	1849
49·1	1·13	0·72	0·58	1·97	6·75	9·5	0·22	0·14	1851
49·4	1·56	0·45	0·52	2·04	6·67	9·6	0·31	0·09	1854
49·7	1·14	1·11	0·60	1·99	6·65	10·0	0·23	0·23	1850
50·9	0·66	0·97	0·56	2·12	6·61	10·3	0·13	0·20	1858
50·8	0·65	0·92	0·53	2·01	6·86	10·3	0·13	0·19	1855
50·0	1·28	0·97	0·55	2·08	6·16	9·6	0·25	0·19	1857
49·9	1·12	0·81	0·57	2·02	6·56	9·8	0·23	0·15	Mean
49·6	1·60	1·18	0·51	2·08	6·56	10·1	0·33	0·24	1862
47·5	1·66	2·51	0·59	2·09	7·54	10·4	0·36	0·55	1861
51·4	0·79	1·34	0·57	2·07	6·25	10·3	0·16	0·27	1848
51·8	0·99	1·31	0·58	2·36	6·01	10·5	0·20	0·27	1852
52·6	1·06	1·00	0·52	2·19	6·23	10·7	0·22	0·20	1856
47·4	2·21	2·37	0·59	1·98	7·26	10·3	0·48	0·51	1860
50·6	1·25	1·06	0·57	2·28	6·64	10·5	0·26	0·22	1859
45·6	2·40	1·25	0·73	2·43	8·38	10·8	0·57	0·30	1853
49·6	1·50	1·50	0·58	2·17	6·70	10·4	0·29	0·30	Mean
46·0	2·37	0·86	0·60	1·75	5·37	7·2	0·37	0·13	1863
45·9	2·70	0·86	0·58	1·72	5·93	7·7	0·45	0·14	1849
49·6	1·46	0·64	0·64	1·93	5·89	9·0	0·26	0·11	1851
46·1	2·23	0·72	0·58	1·74	6·15	7·9	0·38	0·12	1854
49·2	1·54	0·60	0·68	1·99	6·18	9·2	0·29	0·11	1850
46·7	2·78	1·01	0·77	1·99	6·35	8·9	0·53	0·19	1858
51·3	0·78	1·42	0·63	2·11	5·98	10·0	0·15	0·28	1848
47·0	2·12	1·51	0·72	1·90	5·16	7·7	0·34	0·25	1857
47·7	2·00	0·95	0·64	1·87	5·84	8·3	0·36	0·16	Mean
47·5	1·58	0·97	0·68	1·97	6·61	9·1	0·30	0·18	1855
44·3	2·91	1·80	0·65	1·98	6·30	8·2	0·54	0·33	1862
52·9	0·61	1·04	0·64	2·33	5·15	9·7	0·11	0·19	1852
50·1	1·00	1·11	0·67	2·11	5·88	9·3	0·19	0·20	1856
44·6	2·63	1·68	0·69	2·00	7·12	8·9	0·53	0·34	1861
47·2	2·36	1·17	0·68	2·09	6·09	8·8	0·44	0·22	1859
43·4	3·57	2·60	0·72	1·94	7·38	9·2	0·76	0·55	1860
44·7	2·45	1·82	0·74	1·85	7·09	8·8	0·49	0·36	1853
46·8	2·14	1·52	0·68	2·05	6·32	9·0	0·39	0·28	Mean

other constituents; being, without manure, and with ammonium-salts alone, nearly twice as high on the average of the eight years of low quality of grain as over the eight of higher quality. It is, moreover, remarkable that the grain grown by farmyard manure, which supplies a large amount of available silica, shows a smaller proportion of it in its dry substance than that grown either without manure or by ammonium-salts alone.

It may here be observed that the higher proportion of silica in the dry substance with lower conditions of maturation of the produce, is very marked in the case of the straw also. Thus, with farmyard manure, the average proportion of silica per 1000 dry substance of the straw is 41·7 over the eight years of highest maturation, and over the eight of lowest maturation 44·6; without manure, with the years of best ripening, it is 42·7, and with those of the worst ripening 47·5; and with the ammonium-salts alone it is 32·1 over the eight best, and 37·3 over the eight worst seasons.

This result is quite inconsistent with the usually accepted view that high quality and stiffness of straw depend on high amount of silica. Pierre and Bretschneider have, however, concluded from their experiments that this is not the case, and we have ourselves long maintained a contrary view. In fact, high proportion of silica means relatively low proportion of organic substance produced. Nor can there be any doubt that strength of straw depends on favourable development of the woody substance; and the more this obtains the more will the accumulated silica be, so to speak, diluted—in other words, show a lower proportion to the organic substance. Further evidence will be adduced on this point as we proceed. It may be mentioned, however, that in this neighbourhood, where the straw-plait industry prevails, the complaint during the last few seasons of bad harvests has been that an unusually large proportion of the straw is brittle and breaks in the working; and considering the character of the seasons there can be no doubt that this is associated with low development of the woody matter and high proportion of silica.

It will be well to go a little more into detail in reference to other individual mineral constituents; and first as to the proportion of potash in the dry substance of the grain in the different seasons.

With each condition as to manuring, there is not only a lower average proportion of potash, but a much greater uniformity in the proportion, in the eight seasons of higher, than in the eight of lower quality of grain. The chief exceptions to uniformity in the eight years of higher quality are, with farmyard manure in 1863, without manure in 1863 and 1857, and with ammonium-salts again in 1863 and 1857. In these years the proportion of potash was, though not

actually the lowest in the 16 years, considerably below the average. The season of 1863, which shows a low proportion of potash under each of the three conditions as to manuring, was not only the one of the greatest luxuriance, as shown by the yield of total produce (grain and straw), but it was the one of highest produce of grain throughout the 40 years of the experiments 1844 to 1883 inclusive, both in the experimental field and in the country at large. The other season of low proportion of potash in the grain, 1857, was one of lower than average growth of straw; but, owing to high summer temperature and less than the average fall of rain, the season was very favourable for seed-formation; but with some excess of rain about harvest time the weight per bushel was low. Both these seasons of low proportion of potash were therefore seasons of high grain productiveness, and the low proportion of potash is due, not to deficiency of potash, but to high accumulation of organic substance. In fact in 1863, the quantity of potash per acre in the total crop, under each condition of manuring, was more than over the average of seasons; and in 1857 the quantity per acre in the grain was more than in the grain on the average of seasons.

Very different, however, were the conditions of season, and of crop, under which absolutely the lowest proportion of potash in the grain throughout the 16 years was found. With each condition as to manuring, the actually lowest proportion of potash in the dry substance of the grain was in 1852, which yielded less than the average amount of both grain and straw, lower than average proportion of grain to straw, and grain of very low weight per bushel. The spring had been dry, cold, and backward, the early summer rainy and cold, and the seed-forming and maturing period variable, with a good deal of hot weather, but some heavy storms. Here then the low proportion of potash in the grain (and it was very low in the straw also, even on the farmyard manure plot) was due to defective conditions of season, for growth, for seed-formation, and for maturation.

It is remarkable that whilst it is with good seasons that we have a comparatively uniform and low proportion of potash in the dry substance of the grain, it is with a very bad season that we have actually the lowest proportion; and it is again in nearly the worst season of our whole series of 40 years that there is actually the highest proportion of potash in the dry substance. Thus, in 1853 we have, with farmyard manure and without manure, the highest, and with ammonium-salts alone, very high proportion of potash in the grain, with at the same time the lowest amount of produce, the lowest proportion of grain to straw, and the lowest weight per bushel of grain throughout the 16 years. The conditions of growth were that, owing to an extremely wet autumn and winter, the seed could not be sown

until the spring; the spring was unseasonably cold and wet, and the summer colder than the average, and very wet. The high proportion of potash was thus due to defective accumulation of organic substance under the influence of unfavourable climatic conditions.

These details as to the proportion of potash in the dry substance of the grain illustrate in a very striking manner the greater influence of season than of manuring on the mineral composition of the grain. With favourable seasons there is comparatively little variation; but with unfavourable seasons there is very great variation, sometimes much lower, but sometimes much higher, and on the average higher proportions of potash than in favourable seasons. Nor is there evidence that there is, comparing one season with another, high proportion of either lime, magnesia, or soda, with low proportion of potash, or *vice versâ*. Comparing the average results of one plot with those of another, however, there is, with the small produce without manure, even a rather higher proportion of both potash and lime, but lower of magnesia than with farmyard manure. With ammonium-salts alone, on the other hand, where there is great exhaustion of mineral constituents having regard to the amount of crop grown, there is a distinctly lower average proportion of both potash and magnesia, and a rather high proportion of lime. The conclusion is, that with normal maturation there is nearly uniform composition, and that the deviations from normal mineral composition are associated with deviations from normal development of the organic substance.

It will be well to call attention, though more briefly, to the connection between the character of the produce and the proportion of phosphoric acid it contains. As with potash, so also with phosphoric acid, there is with each of the three conditions as to manuring, a lower average proportion in the dry substance of the grain over the eight better, than over the eight worse seasons; and the proportion is generally the lowest in the individual seasons of high quality of grain. There is, however, with lower average and lower individual proportions of phosphoric acid in the better seasons, a wider range of variation than in the seasons of lower quality of grain; and also a wider range of variation than in the case of the potash. In the case of the farmyard manure plot at any rate, it cannot be supposed that the low proportions of phosphoric acid in the dry substance of the grain of the better seasons are due to deficient supply. The indication is indeed, as with the potash, that the low proportion with high quality of grain is the result of enhanced accumulation of organic substance, by which the proportion of the mineral constituents is reduced. On this view, a relatively low proportion of any one constituent may be due to its favourable action, and will by no means necessarily imply either deficient supply, or that it has been without beneficial effect.

Comparing, however, the results for the three different plots with one another, the question of supply or exhaustion obviously comes in. It is seen that the proportion of phosphoric acid in the dry substance of the grain is lower without manure than with farmyard manure, and much lower still with ammonium-salts alone. Other evidence will be given further on, showing that with ammonium-salts alone there was doubtless very abnormal exhaustion of phosphoric acid. Further, there is unmistakeable evidence of increase in the proportion of sulphuric acid with the decrease in that of phosphoric acid, though not in amount to compensate for the deficiency.

The question here arises, how far the phosphoric acid and sulphuric acid found in the ash are due to the oxidation of phosphorus and sulphur in the burning? The evidence at command leads to the conclusion that the existing phosphorus and sulphur are at any rate only in part so oxidated. On the other hand, the evidence goes to show that sulphuric acid is liable to be expelled in the incineration, in presence of acid phosphates, or much silica, or to be reduced by charcoal if there be not sufficiently free access of air. In the method of burning adopted at Rothamsted, there is probably a minimum liability to loss from such reduction. As bearing upon the question of the probability of loss of sulphuric acid (and chlorine) by expulsion in presence of acid phosphates or silica, it may be mentioned that, excluding the ferric oxide on the one hand, and the silica on the other, and calculating the whole of the phosphoric acid as tribasic, the grain-ashes show more than one and a half time as much acid as base; and even calculating the whole of the phosphoric acid, whether combined with alkalis or earths, as only bibasic, there is still an excess of acid. On the other hand, the straw-ashes, calculated in the same way, show a considerable excess of base, even when the whole of the phosphoric acid is reckoned as tribasic; but they contain more than 60 per cent. of silica. The question arises, therefore, whether carbonic acid (from organic acids or carbonates as such), and some sulphuric acid and chlorine, have not been expelled in the burning; in the case of the grain-ashes, in the presence of acid phosphates, and in that of the straw-ashes, in the presence of an excess of silica.

Referring to the control of ash-analyses, Bunsen maintains that by treating the ash with carbonic acid, and subsequent evaporation, all the bases present are converted into neutral salts; and that the results of the analysis can only be considered satisfactory, when the sum of the quotients obtained by dividing the weights of the individual bases by their equivalent weights, is very approximately equal to the sum of the quotients of the amounts of the acids found, divided by their equivalents. In other words, acids and bases must stand in

such relation to one another as to form neutral salts without leaving any residue.

It seems difficult to suppose that the analyses of the ashes of wheat-grain and wheat-straw, such as those recorded in this paper, could be so proved to be correct. Thus, in the case of the grain-ashes, the basicity of the phosphoric acid must be calculated as may be required to give neutral salts; and in the case of the straw-ashes as much of the silica as may be required must be brought in.

Unfortunately we have not complete analyses of the ash of the separate mill-products of wheat-grain, but in our former paper (this Journal, 1857) we gave the amounts of nitrogen, and of total ash, in some series of such products, and the amount of phosphoric acid and magnesia in selected cases. Dempwolf has, however, given most of the constituents in a complete series of mill-products (*Ann. Chem. Pharm.*, 1869, **149**, 343), and so far as the constituents, nitrogen, phosphoric acid, and magnesia, which we also determined, are concerned, his results and our own are generally accordant. Within the range of the white flours, there is very generally a slight increase in the percentage of nitrogen proceeding from the finer to the coarser. There is a more marked increase in the percentage of nitrogen in the more branny products, though it is not quite so high in the purest bran as in the products next above it in the series; the greatest concentration of nitrogenous substances being immediately below the pericarp itself.

Referring to the distribution of the several ash-constituents, it may be stated that, according to the data referred to, the amount of potash and of lime in proportion to a given weight of organic substance increases somewhat more rapidly than does that of the nitrogen, proceeding from the finer to the coarser white flours, that of magnesia does so in a greater degree still, and that of the phosphoric acid in about the same degree as the potash. The proportion of all the constituents mentioned is very much greater in the more branny portions. Thus, the proportion of potash is about 10 times as high in the dry substance of the bran as in that of the finer flours; the proportion of lime is 4 or 5 times as high; that of magnesia 15 to 20 times, and that of phosphoric acid more than 10 times as high. Our own experiments showed about 15 times as much magnesia, and about 10 times as much phosphoric acid in the dry substance of the bran as in that of the white flours. Again, experiments of W. Mayer (*Ann. Chem. Pharm.*, 1857) showed about 14 times as much phosphoric acid in the dry substance of bran as in that of the finest flour.

In fact the more the cereal grain, which is characteristically a starchy product, is perfectly matured, the higher will be the proportion of flour, as a rule the lower will be the proportion of nitrogenous

substances, the lower that of the bran, and the higher that of starch. It is obvious from the facts quoted above, that the more these characters are developed, the lower should be the proportion of the mineral constituents in the total grain; and the results which have been discussed have consistently shown a lower proportion of mineral constituents in the produce of the seasons of favourable maturation.

Table III (pp. 12—13) also shows, as has been referred to, a generally lower percentage of nitrogen in the better matured grains, that is, in those in which more starch has been accumulated. In reference to this point, it may be stated that in 1847 we took samples of a growing wheat crop at different stages of its progress, commencing on June 21, and determined the dry matter, ash, and nitrogen in them. Calculation of the results showed that whilst during little more than five weeks from June 21, there was comparatively little increase in the amount of nitrogen accumulated over a given area, more than half the total carbon of the crop was accumulated during that period. Consistently with this, Professor R. C. Kedsie, and the late Professor R. F. Kedsie have recently shown by a series of experiments in which they partially analysed samples of a wheat crop cut on 21 consecutive days, commencing June 26, 1879, that with increase in the weight of the kernels there was, especially in the earlier stages, a decrease in the percentages of nitrogen, cellulose, and mineral matter; whilst calculated per acre at the different periods, there was an increase in the actual amount of nitrogen stored up over a given area up to a given point, but a considerably greater increase in the quantity of carbohydrates accumulated in the same time over the same area.

Again, in a very comprehensive investigation of the composition of American wheats, conducted by Mr. Clifford Richardson, under the auspices of the Department of Agriculture at Washington, he finds a generally low average percentage of albuminoïds in American as compared with European wheats; and he concludes that this is indication of inferiority of quality, in many cases due to deficient supply of nitrogen by the soil. It is more probably due to enhanced formation of starch under the influence of high ripening temperature. In our former paper, we discussed the point as far as the data then at command permitted, and we concluded that high percentage of total nitrogenous substance was by no means a characteristic of the wheats held in the highest estimation either by the miller or the baker; and that so far as both the baker and the consumer are concerned, the condition of the nitrogenous matters is of more importance than their total amount. Comparing one description of wheat with another, the one with a relatively high percentage of nitrogen may be the better, provided the grain be at the same time fully ripened, and not too horny. But when the percentage exceeds a certain limit, the grain is

generally either too hard, or there is deficient storing up of starch, and an unfavourable condition of the nitrogenous substances. In fact, comparing the grain grown from the same description of seed, but on different soils, or in different seasons, high percentage of total nitrogenous matter is almost invariably coincident with inferior maturation.

The next point to consider is the bearing of the results relating to the three plots, as to the influence of full supply or of exhaustion on the mineral composition of the grain.

Table IV (pp. 22—23) shows the average amounts obtained *per acre*, of grain, straw, and total produce, also of nitrogen, ash, and each mineral constituent in them, over the first eight, the second eight, and the sixteen years, under each of the three conditions as to manuring.

Table V (pp. 24—25) shows the quantity of nitrogen, pure ash, and each ash-constituent, *per* 1000 *dry matter of produce* (grain, straw, and total) over the first eight, the second eight, and the sixteen years respectively, for each of the three plots.

It is difficult to say whether the first eight or the second eight seasons were on the average the more favourable for the crop. The first eight included perhaps more fairly good, and one or two very good seasons, but two very bad ones; whilst the second eight included the best season of the sixteen—indeed of the forty up to the present time, some others of more than average favourable character, and only one exceptionally bad one. Under these circumstances, farmyard manure, with its annual accumulation, yielded more grain, more straw, and considerably more of both nitrogen and total mineral matter, over the second than over the first eight years. Without manure, there was almost identically the same amount of grain, rather less straw, and rather less both of nitrogen and of mineral matter, over the second eight years. With ammonium-salts alone, with great relative deficiency of mineral supply, there was less corn, less straw, less mineral matter, and in a more marked degree less nitrogen in the crops, over the second eight years. It is to be observed that there was this deficiency of nitrogen in the crop over the later period, notwithstanding a great excess was annually supplied by manure.

The average quantities of total mineral constituents yielded per acre per annum over the sixteen years, on the three plots, were as follows:—

	In grain. lbs.	In straw. lbs.	Total. lbs.
By farmyard manure	36·3	201·1	237·4
Without manure	16·6	89·5	106·1
With ammonium-salts alone..	23·0	119·2	142·2

Thus, considerably more total mineral matter is taken up under the

influence of the ammonium-salts than without manure, but more than twice as much is taken up under the influence of farmyard manure as without manure. The last three columns of Table IV show a considerable increase in the amount of every constituent taken up under the influence of the ammonium-salts, and a still greater increase (excepting of soda) with the farmyard manure. The greatest *proportional* increase of constituents taken up on the ammonium-salts plot is in the lime, potash, magnesia, soda, sulphuric acid, and chlorine, and the least in phosphoric acid. With farmyard manure, by far the greatest increase is in the potash, which is more than two and a half times as much as without manure; there is also about twice as much magnesia, and more than twice as much lime, phosphoric acid, sulphuric acid, soda, and silica, and nearly four times as much chlorine.

Comparing on each plot the yield over the second eight years with that over the first eight, without manure the produce of grain contains nearly identical amounts of each ash-constituent over the two periods; but even showing a tendency to excess in magnesia, phosphoric acid, and silica, over the second period. The result is, however, different with the straw and total produce; both of which show more or less deficiency of every constituent excepting lime, which increases considerably, whilst ferric oxide and soda also show a tendency to increase. Deficiency in the straw, and with it in the total produce, that is, in the amount taken up and retained by the entire plant, or rather crop, is indication of deficient source, notwithstanding there may be no falling off in the contents of the grain.

With farmyard manure, with its excessive supply, there is over the second period compared with the first, more or less increase in every constituent in grain, in straw, and in total produce, with the single exception of sulphuric acid, which is very slightly in relative defect in the straw and total produce over the second period. In the grain, the constituents in most marked increased amount are the typical ones potash and phosphoric acid; in the straw, they are potash and silica; and in total produce, potash, phosphoric acid, and silica.

With ammonium-salts alone for so many years in succession, there is, over the second period, in the grain, only slight deficiency of potash and magnesia, a greater deficiency of phosphoric acid, and a tendency to increase in lime, sulphuric acid, and silica. In the straw and total produce, however, there is more marked deficiency in every constituent excepting sulphuric acid; and it is the most marked in the potash, the phosphoric acid, the chlorine, and the silica; the chlorine especially, although it is liberally supplied in the ammonium chloride.

That chlorine, and other constituents of possibly little other use than as carriers, may be taken up and returned to the soil, especially under certain conditions of weather, would seem not improbable. The

TABLE IV.

Average Amounts, *per Acre*, of Grain, Straw, Total Produce, Nitrogen, Ash-Constituents, and Total Ash (pure), over the First Eight, the Second Eight, and the Sixteen years, under each of the Three Conditions as to Manuring.

	Plot 2. Farmyard manure.		Plot 3. Unmanured.		Plot 10*a*. Ammonium salts alone.		16 years, 1848—'63.		
	First 8 years, 1848—'55.	Second 8 years, 1856—'63.	First 8 years, 1848—'55.	Second 8 years, 1856—'63.	First 8 years, 1848—'55.	Second 8 years, 1856—'63.	Plot 2. Farmyard manure.	Plot 3. Unmanured.	Plot 10*a*. Ammonium salts alone.
Grain to 100 straw	56·1	60·8	58·2	60·9	56·5	58·0	58·6	59·5	57·2
Weight per bushel of grain, lbs.	60·1	59·8	57·8	57·0	58·1	56·0	60·0	57·4	57·1
Quantities per Acre—Grain, lbs.									
Fresh produce	1929	2380	990	990	1578	1471	2154	990	1524
Dry matter	1608	2000	823	826	1319	1239	1804	825	1279
Nitrogen	29·2	37·0	15·9	15·4	29·6	25·8	33·1	15·7	27·5
Ash-constituents. Ferric oxide	0·28	0·31	0·16	0·17	0·20	0·21	0·30	0·16	0·20
Lime	0·84	1·03	0·47	0·47	0·83	0·84	0·94	0·47	0·84
Magnesia	3·59	4·50	1·68	1·75	2·55	2·41	4·04	1·72	2·48
Potash	10·17	12·73	5·48	5·45	7·97	7·48	11·45	5·46	7·70
Soda	0·20	0·23	0·10	0·11	0·12	0·12	0·22	0·10	0·12
Phosphoric anhydride	16·68	20·98	8·13	8·42	11·57	10·27	18·83	8·28	10·92
Sulphuric anhydride	0·27	0·27	0·20	0·21	0·41	0·53	0·27	0·21	0·47
Chlorine	0·01	0·01	0·01	0·01	0·03	0·09	0·01	0·01	0·06
Silica	0·26	0·29	0·15	0·21	0·22	0·31	0·27	0·18	0·26
Total	32·30	40·35	16·38	16·80	23·90	22·21	36·33	16·59	23·05
Deduct O = Cl	—	—	—	—	0·01	0·02	—	—	0·01
Total	32·30	40·35	16·38	16·80	23·89	22·19	36·33	16·59	23·04

Quantities per Acre—Straw, lbs.

Fresh produce	3442	3918	1701	1626	2790	3536	3677	1668	2648
Dry matter	2858	3307	1405	1375	2338	2141	3082	1390	2240
Nitrogen	13·7	13·8	7·6	6·5	13·5	11·8	13·5	7·0	15·1
Ash-constituents. Ferric oxide	0·98	1·07	0·72	0·75	0·75	0·71	1·02	0·73	0·73
Lime	7·87	8·51	2·97	3·93	7·22	7·02	8·19	3·45	7·12
Magnesia	3·01	3·04	2·30	1·46	2·27	1·95	3·03	1·88	2·11
Potash	33·22	40·18	13·89	11·96	21·46	17·57	36·70	12·93	19·52
Soda	0·99	1·02	0·47	0·51	1·53	1·17	1·00	0·49	1·34
Phosphoric anhydride	7·51	7·59	3·77	3·96	3·76	3·53	7·55	3·36	3·65
Sulphuric anhydride	5·98	5·84	2·83	2·73	4·62	4·78	5·91	2·78	4·70
Chlorine	5·75	6·93	1·78	1·58	4·30	2·72	6·34	1·68	3·51
Silica	120·45	145·13	64·42	60·68	81·20	73·85	132·79	62·55	77·27
Total	185·76	219·31	93·15	86·56	127·10	112·80	202·53	89·85	119·95
Deduct O = Cl	1·30	1·56	0·40	0·36	0·97	0·62	1·43	0·38	0·79
Total	184·46	217·75	92·75	86·20	126·13	112·18	201·10	89·47	119·16

Quantities per Acre, Total Produce (Grain and Straw), lbs.

Fresh produce	5371	6293	2691	2616	4368	4007	5831	2653	4187
Dry matter	4466	5307	2228	2201	3657	3380	4886	2215	3519
Nitrogen	42·9	50·3	23·5	21·9	48·1	37·1	46·6	22·7	42·6
Ash-constituents. Ferric oxide	1·26	1·38	0·88	0·92	0·95	0·92	1·32	0·89	0·93
Lime	8·71	9·54	3·44	4·40	8·05	7·86	9·13	3·92	7·96
Magnesia	6·60	7·54	3·98	3·21	4·82	4·86	7·07	3·60	4·59
Potash	43·39	52·91	19·37	17·41	29·43	25·00	48·15	18·39	27·22
Soda	1·19	1·25	0·57	0·62	1·64	1·29	1·22	0·59	1·46
Phosphoric anhydride	24·19	28·57	11·90	11·38	15·33	13·80	26·38	11·64	14·57
Sulphuric anhydride	6·25	6·11	3·03	2·94	5·03	5·31	6·18	2·99	5·17
Chlorine	5·76	6·94	1·79	1·59	4·33	2·81	6·35	1·69	3·57
Silica	120·71	145·42	64·57	60·89	81·42	73·66	133·06	62·73	77·53
Total	218·06	259·66	109·53	103·36	151·00	135·01	238·86	106·44	143·00
Deduct O = Cl	1·30	1·56	0·40	0·36	0·98	0·64	1·43	0·38	0·80
Total	216·76	258·10	109·13	103·00	150·02	134·37	237·43	106·06	142·20

TABLE V.

Quantities of Nitrogen, Ash-Constituents, and Total Ash (pure), *per* 1000 *Dry Matter of Produce* (Grain, Straw, and Total) over the First Eight, the Second Eight, and the Sixteen Years, under each of the Three Conditions as to Manuring.

	Plot 2. Farmyard manure.		Plot 3. Unmanured.		Plot 10*a*. Ammonium salts alone.		16 years, 1848—'63.		
	First 8 years, 1848—'55.	Second 8 years, 1856—'63.	First 8 years, 1848—'55.	Second 8 years, 1856—'63.	First 8 years, 1848—'55.	Second 8 years, 1856—'63.	Plot 2. Farmyard manure.	Plot 3. Unmanured.	Plot 10*a*. Ammonium salts alone.
Grain to 100 straw	56·1	60·8	58·2	60·9	56·5	58·0	58·6	59·5	57·2
Weight per bushel of grain, lbs.	60·1	59·8	57·8	57·0	58·1	56·0	60·0	57·4	57·1
Per 1000 *Dry Matter of Grain.*									
Fresh produce	1200	1190	1203	1199	1196	1187	1194	1200	1191
Nitrogen	18·2	18·5	19·3	18·6	22·4	20·4	18·3	19·0	21·5
Ash-constituents. Ferric oxide	0·17	0·16	0·19	0·21	0·15	0·16	0·16	0·20	0·16
Lime	0·52	0·51	0·57	0·57	0·63	0·68	0·52	0·57	0·65
Magnesia	2·24	2·25	2·05	2·12	1·93	1·94	2·24	2·08	1·93
Potash	6·32	6·36	6·66	6·59	6·05	6·00	6·35	6·62	6·02
Soda	0·12	0·12	0·12	0·13	0·09	0·10	0·12	0·13	0·10
Phosphoric anhydride	10·38	10·49	9·88	10·20	8·77	8·29	10·44	10·03	8·54
Sulphuric anhydride	0·17	0·14	0·25	0·25	0·31	0·43	0·15	0·25	0·37
Chlorine	0·01	0·01	0·01	0·01	0·02	0·07	0·01	0·01	0·04
Silica	0·16	0·14	0·18	0·26	0·16	0·25	0·15	0·22	0·21
Total	20·09	20·18	19·91	20·34	18·11	17·92	20·14	20·11	18·02
Deduct O = Cl	—	—	—	—	—	0·02	—	—	0·01
Total	20·09	20·18	19·91	20·34	18·11	17·90	20·14	20·11	18·01

Per 1000 Dry Matter of Straw.

Fresh produce	1204	1183	1211	1182	1193	1185	1193	1196	1189
Nitrogen	4·8	4·0	5·4	4·7	7·9	5·5	4·4	5·0	6·7
Ash-constituents. Ferric oxide	0·34	0·32	0·51	0·54	0·32	0·33	0·33	0·53	0·33
Lime	2·75	2·57	2·11	2·86	3·08	3·28	2·66	2·48	3·18
Magnesia	1·05	0·92	1·63	1·06	0·97	0·91	0·98	1·35	0·94
Potash	11·62	12·15	9·89	8·70	9·18	8·21	11·91	9·30	8·71
Soda	0·35	0·31	0·33	0·38	0·65	0·55	0·32	0·35	0·60
Phosphoric anhydride	2·63	2·30	2·69	2·15	1·61	1·65	2·45	2·42	1·63
Sulphuric anhydride	2·09	1·77	2·01	1·98	1·98	2·23	1·92	2·00	2·10
Chlorine	2·01	2·10	1·27	1·15	1·84	1·27	2·06	1·21	1·57
Silica	42·15	43·88	45·85	44·13	34·73	34·26	43·08	45·00	34·49
Total	64·99	66·32	66·29	62·95	54·36	52·69	65·71	64·64	53·55
Deduct O = Cl	0·45	0·47	0·28	0·26	0·41	0·29	0·46	0·27	0·35
Total	64·54	65·85	66·01	62·69	53·95	52·40	65·25	64·37	53·20

Per 1000 Dry Matter of Total Produce (Grain and Straw).

Fresh produce	1203	1186	1208	1189	1194	1186	1193	1198	1190
Nitrogen	9·6	9·5	10·6	10·0	13·2	11·0	9·5	10·3	12·1
Ash-constituents. Ferric oxide	0·28	0·26	0·39	0·42	0·26	0·27	0·27	0·41	0·27
Lime	1·95	1·80	1·54	2·00	2·20	2·33	1·87	1·77	2·26
Magnesia	1·48	1·42	1·79	1·46	1·32	1·29	1·45	1·62	1·30
Potash	9·71	9·97	8·70	7·91	8·05	7·40	9·85	8·30	7·74
Soda	0·27	0·24	0·26	0·28	0·45	0·38	0·25	0·27	0·42
Phosphoric anhydride	5·42	5·38	5·34	5·17	4·19	4·08	5·40	5·26	4·14
Sulphuric anhydride	1·40	1·15	1·36	1·33	1·37	1·57	1·27	1·35	1·47
Chlorine	1·29	1·31	0·80	0·72	1·19	0·83	1·30	0·76	1·01
Silica	27·03	27·40	28·98	27·67	22·26	21·79	27·23	28·32	22·03
Total	48·83	48·93	49·16	46·96	41·29	39·94	48·89	48·06	40·64
Deduct O = Cl	0·29	0·30	0·18	0·16	0·27	0·19	0·29	0·17	0·23
Total	48·54	48·63	48·98	46·80	41·02	39·75	48·60	47·89	40·41

experiments of Anderson and ourselves with beans show a considerable reduction in the amount of mineral matter in the crop of a given area during the last few weeks, but in the case of this crop there is a considerable fall of leaf at this period. Dr. Anderson's results with wheat do not show such reduction, either of total mineral matter, potash, phosphoric acid, or silica. E. Wolff's experiments with potatoes showed considerable reduction in the amounts of nitrogen, total ash, lime, magnesia, and chloride of sodium, during the last five weeks, but there was also considerable loss of total dry substance. His experiments with mangel-wurzel, red clover, lucerne, and rape showed, with immaterial exceptions, considerable gain of all constituents to the end of the period quoted, when, however, such crops would not have ripened. In one experiment with barley, there was gain of every constituent to the end; in a second there was gain in all excepting potassium chloride, and potash, both of which showed a loss in the last stage; and in a third there was considerable reduction in total ash, chiefly in magnesia, potassium chloride, and potash. In two experiments with oats, there was gain in total ash, but considerable loss of potash. In an experiment with wheat, though there was a gain in total ash, there was a considerable reduction of potash. In experiments on barley, by Schéven, there was gain of nitrogenous, non-nitrogenous, and total dry substance to the end, also gain of total ash, phosphoric acid, soda, and chlorine; but reduction in potash, lime, and magnesia. In experiments with barley, Bretschneider found gain in total dry matter, nitrogen, total ash, and most individual ash-constituents to the end, but during ripening a slight reduction of potash and chlorine was indicated. According to Joulie's experiments, there is a considerable reduction in the amount, especially of potash, in the total wheat-plant during the seed-forming and ripening periods. Marie-Davy concluded that during the ripening period plants expel superfluous matters by their roots. Pierre, in experiments with rape, found a reduction in the amounts of nitrogen, and most ash-constituents, excepting phosphoric acid, in the later stages; but he notes that leaves had fallen. In his experiments with wheat, the results were very similar. In experiments with oats, Arendt did not find any appreciable reduction either in total ash, or in ash-constituents, excepting soda. In experiments with wheat, Dehérain found no reduction until the crop was ripe, but a good deal afterwards; and here the question arises whether there was not loss by birds, or otherwise than by excretion by the plant. In his experiments with oats, the results were irregular, owing to unfavourable weather. Upon the whole, it would seem that satisfactory evidence is still wanting on the point; and it is probable that the result will be considerably influenced by the conditions of the weather.

Recurring to the results as to the yield *per acre* of the several con-

stituents (in grain and straw) over the first and second half of the sixteen years, as given in Table IV (pp. 22—23), without manure there is indicated a comparatively small relative exhaustion of both potash and phosphoric acid, and with ammonium-salts a greater exhaustion of both.

Table V (pp. 24—25), which gives the amount of each constituent *per* 1000 *dry substance* of grain, straw, and total produce, shows the degree in which the composition is affected by the excess or deficiency of supply.

Taking the mean result for the sixteen years in each case, 1000 dry substance of grain shows a rather higher proportion of nitrogen without manure than with farmyard manure, and higher still with ammonium-salts alone. It shows almost identical amounts of total mineral constituents under the influence of full supply of them by farmyard manure, and of exhaustion of both nitrogen and mineral constituents without manure. There is, however, a considerable deficiency under the very abnormal exhaustion of mineral constituents, when ammonium-salts alone are used for so many years in succession. The dry substance of the unmanured grain contains a rather higher proportion of potash, rather less magnesia, and less phosphoric acid, than that grown by farmyard manure. The relative deficiency in the dry substance of the grain grown by ammonium-salts is partly in potash, but mainly in phosphoric acid, which is only in small part compensated by an increased amount of sulphuric acid. Magnesia is also in slight relative defect.

The composition of the straw, which much more directly indicates relative supply or exhaustion, shows much wider variation under the three different conditions as to manuring. Compared with the straw grown with farmyard manure, that grown without manure contains, per 1000 dry substance, considerably less potash, but otherwise there is but little difference, excepting that it contains notably less chlorine and more silica. With ammonium-salts alone, there is a still greater decrease in the amount of potash in the dry substance of the straw, partly compensated by more lime. There is also considerably less phosphoric acid, but rather more sulphuric acid, and there is much less silica than either with farmyard manure or without manure.

Comparing the average composition of the produce of the second eight years with that of the first, with farmyard manure, the mineral composition of the dry substance of the grain is almost absolutely identical over the two periods. Without manure, again, it is very nearly so, the figures showing, however, a tendency to a rather lower proportion of potash over the latter half of the total period, with at the same time slightly more magnesia, and also more phosphoric acid; conditions which are indicative of less perfect maturation, that is, less flour in proportion to bran. With ammonium-salts, the mineral com-

position of the grain, though showing, compared with that of the other plots, a marked deficiency in potash and magnesia, and especially in phosphoric acid, shows very little difference comparing the second eight years with the first. So far as the bases are concerned, the average proportion in the dry substance of the grain is almost identical over the two periods; but there is an obvious tendency over the later period to decrease in phosphoric acid, and with this to increase in sulphuric acid and in silica.

The composition of the dry substance of the straw, which has been seen to vary considerably as between plot and plot, varies also much more than does that of the grain over the two periods, but still comparatively little. With farmyard manure, the chief difference is that there is a somewhat larger proportion of potash and silica, and somewhat less phosphoric acid and sulphuric acid over the second period, differences probably due to season and character of growth depending thereon, rather than to soil supply independently of these. Without manure, the chief indication is a relative deficiency of potash and magnesia, partly compensated by more lime, also a deficiency of phosphoric acid over the second period. With ammonium-salts alone, the most marked difference is a relative deficiency of potash over the later period.

Thus, although it has been shown that there is much wider range of variation in the mineral composition of wheat-grain according to season than according to manure, it is seen that there is nevertheless an obvious difference in the average composition of the grain under the three very different conditions as to manuring; but with each there is almost identical average composition over the first and second half of the period of sixteen years. The grain grown by the ammonium-salts alone shows exhaustion both of potash and phosphoric acid, but especially the latter. The condition of exhaustion here is, however, quite abnormal, and the results as a whole point to great uniformity in the mineral composition of the grain under varying conditions as to manure, provided only that it is perfectly and normally ripened. It will be seen, too, that the lowest average proportion of nitrogen is in the grain grown by farmyard manure, notwithstanding its liberal supply of it, again indicating that the composition, and especially high or low percentage of nitrogen, is much more dependent on maturation than on full or limited supply by the soil. The next series of results will further illustrate the influence of season and manuring on the composition of the wheat crop in selected seasons, and with a greater variety of manuring.

Second Series of Analyses.

This series includes the results obtained under nine different con-

ditions as to manuring, each in two unfavourable and in two favourable seasons for the crop:—

The conditions as to manuring were:—

Plot 2. Farmyard manure, every year.
Plot 3. Unmanured, every year.
Plot 5*a*. Mixed mineral manure,* alone.
Plot 7*a*. Mixed mineral manure,* and ammonium-salts.†
Plot 10*a*. Ammonium-salts, alone.
Plot 11*a*. Ammonium-salts and superphosphate of lime.‡
Plot 12*a*. Ammonium-salts, superphosphate, and sulphate of soda.§
Plot 13*a*. Ammonium-salts, superphosphate, and sulphate of potash.‖
Plot 14*a*. Ammonium-salts, superphosphate, and sulphate of magnesia.¶

It will be seen that, besides the conditions of manuring to which the first series of analyses relates, this series includes the results obtained on six other plots with widely different, but strictly comparable, conditions of mineral or ash-constituent supply. Thus, we have ammonium-salts alone; the same with superphosphate; the same with superphosphate and soda-salt; the same with superphosphate and potash-salt; the same with superphosphate and magnesia-salt; and the same with superphosphate, potash-, soda-, and magnesia-salt. The seasons selected were 1852, 1856, 1858, and 1863.

1852 was the ninth season from the commencement of the experiments, and the first of the twelve which comprise the four to which the series of analyses now under consideration relates. The winter had been favourable upon the whole; but the spring was dry, cold, and backward; the early summer was rainy and cold; and the maturing period variable, with a good deal of hot weather, but some heavy storms. Without manure, the produce of grain was the lowest that

* The mixed mineral manure was composed per acre as follows:—1852–1858, sulphate of potash 300 lbs., sulphate of soda 200 lbs., sulphate of magnesia 100 lbs.; 1859 and since, sulphate of potash 200 lbs., sulphate of soda 100 lbs., sulphate of magnesia 100 lbs.; also superphosphate of lime made as described below.

† Ammonium-salts, in all cases 200 lbs. sulphate, and 200 lbs. muriate of ammonia of commerce, per acre.

‡ Superphosphate of lime (per acre), in all cases made from bone-ash 200 lbs., sulphuric acid (sp. gr. 1·7) 150 lbs., and water.

§ Sulphate of soda, 500 lbs. per acre 1852–1858; two-thirds as much 1859 and afterwards.

‖ Sulphate of potash, 300 lbs. per acre 1852–1858; 200 lbs. 1859 and afterwards.

¶ Sulphate of magnesia, 420 lbs. per acre 1852–1858; two-thirds as much (280 lbs.), 1859 and afterwards.

had been obtained so far, and below the average of the first 20 years. Under the influence of ammonium-salts, whether alone or in conjunction with mineral manures, the produce of grain was very much, and that of straw considerably, below the average obtained by such manures. Finally, the proportion of grain to straw, and the weight per bushel of the grain, were very low.

1856 was the thirteenth season of the experiments. The winter had been mild upon the whole; the early spring was dry and cold, and the remainder cold and wet, the early summer was cold and changeable, then came a short interval of fine and hot weather, succeeded, about the ripening period, by very heavy rains, and prevailing low temperatures. The harvest was also wet and unfavourable. With these conditions of season, the quantity of grain per acre was, excepting without manure, fully equal to, and that of the straw rather over, the average of the 12 years which comprise the four now under consideration. The crops were, however, unevenly and badly ripened, and the proportion of grain to straw, and the weight per bushel of the grain, were low. The season was therefore, upon the whole, not unfavourable to quantity of produce, but it was unfavourable for the full development and maturation of the grain.

1858 was the fifteenth season from the commencement. During the winter, spring, and summer there was, upon the whole, much less than the usual amount of rain; though in February, April, May, and July, there were fair amounts. Throughout the summer, the air was generally drier than usual for the period, and the temperature was generally above the average throughout the spring and summer months, whilst June was unusually hot. Early in the summer, the promise was of great luxuriance, but the warm and dry weather of June checked this tendency, and brought on early maturity; and the harvest weather was favourable. Accordingly, the quantity of straw was generally below the average with parallel conditions as to manuring; but that of the grain was generally above it, especially with high manuring. The proportion of grain to straw was thus above the average, and the weight per bushel of the grain was also above the average.

1863 was the twentieth season of the experiments. The winter and early spring were extremely mild, the plant came early forward, and the rains, though sparing upon the whole, came when needed, whilst the temperature of the summer, though seldom high, was (excepting some night frosts in July) generally sufficient, and the condition of the atmosphere was otherwise favourable. The characters of the season were such as to contribute to a lengthened and almost uninterrupted course of accumulation; and this, the twentieth wheat crop in succession on the same land, was not only the best up to that time

obtained in quantity both of grain and straw, but it is the best obtained during the 40 years to 1883, inclusive. It was also nearly the best as to quality of grain. This extraordinary result was due to almost unchecked growth from the first appearance of the plant above ground, up to the time of harvest, rather than to any extraordinary characteristics at any one or more particular period.

Thus, of the four seasons selected, 1852 was very bad, both as to quantity and quality of produce; 1856 gave fairly average quantity of both grain and straw, but the crop was unevenly ripened, and the weight per bushel was low; 1858 yielded only a moderate amount of total produce, but a more than average proportion and amount of grain, and the weight per bushel was also above the average; lastly, 1863 was the most productive season of the forty of the experiments, as to quantity both of straw and of grain; the weight per bushel of grain was also considerably above the average.

The analytical results (excluding sand and charcoal), are given in detail in Appendix Table X; in Appendix Table XI, the constituents are calculated *per* 1000 *dry substance*, instead of per 100 of ash; and in Appendix Table XII, the quantity of each constituent in the produce *per acre* is given. Referring to these Tables for the study of the details, it will be convenient here to discuss the main bearings of the results by reference to a series of Summary Tables.

In Table VI (p. 32), the mean percentage of selected constituents in the pure ash (of grain and straw respectively), of the nine differently manured plots collectively, is given for each of the four seasons. Thus the effects of season, independently of manure, are shown. By the side of these results are given, as before, the general characters of the produce of each season, as indicated by the average weight per bushel of the grain on the nine plots, the proportion of grain to straw, the amount of total produce (grain and straw) per acre, and finally the mean percentage of nitrogen, and of total mineral matter (or ash) in the dry substance.

It is seen that, as indicated by the weight per bushel of the dressed grain, the quality of the grain was the lowest in the first, and the highest in the last of the four seasons, rising from year to year, taking the seasons in their chronological order. The first two years show lower than average, and the last two higher than average quality. The last two also show very much the higher proportion of grain to straw, that is, a very much higher seed-forming tendency. There can be no doubt, therefore, that so far as quality of produce is concerned the last two seasons were far superior to the first two, which were in fact very bad seasons; whilst the two later seasons were much better, and the last of the four one of very high quality. As to quantity of grain too, there is an increase from the first to the fourth

TABLE VI.

General Characters of the Produce, and *Mean Percentage Composition of the Pure Ash*, in each of the Four Seasons. Means of Nine Differently Manured Plots in each Season.

Harvests.	Weight per bushel of grain, lbs.	Grain to 100 straw.	Produce per acre, lbs.	Per cent. in dry matter.		Per cent. in pure ash.					
				Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Silica.
					Grain.						
1852	56·8	46·8	1390	2·02	1·96	3·17	12·7	28·4	52·9	0·42	0·92
1856	57·4	53·9	1832	1·98	1·92	2·92	11·3	30·1	52·8	0·68	1·00
1858	61·4	66·4	1993	1·96	1·96	3·10	10·4	33·2	50·3	1·06	0·73
1863	62·6	65·8	2761	1·66	1·75	3·01	10·9	33·1	49·9	1·26	0·66
					Straw.						
1852	56·8	46·8	2967	0·59	6·10	4·80	1·72	12·0	3·39	2·44	72·7
1856	57·4	53·9	3397	0·39	5·27	5·00	1·45	14·7	3·48	3·22	68·5
1858	61·4	66·4	3003	0·46	5·59	5·65	1·71	19·8	3·08	5·03	59·9
1863	62·6	65·8	4197	0·32	5·65	5·48	1·72	17·2	2·55	3·47	65·7

season, the last yielding about twice as much as the first, and about one and half time as much straw.

Coincidently with these general agricultural characters of great superiority in the produce of 1863, there is by far the lowest average percentage of both nitrogen and mineral matter (ash), in the dry substance of the grain. In the dry substance of the straw, the percentage of mineral matter is not specially low, but that of the nitrogen is very low, both actually and relatively. The description of the seasons already given shows that the fairly good season of 1858 was one of early but checked, and finally, limited luxuriance, with high seed-forming tendency, in proportion to the amount of plant; whilst that of 1863 was one of very great luxuriance throughout the growing period, with very high seed-forming tendency supervening. It will afterwards be seen, indeed, that the total crop of 1863 contained about one and a half time as much mineral matter per acre, and also considerably more nitrogen, than that of either of the other seasons; yet the percentage of both was much lower in the grain, and that of the nitrogen lower also in the straw, than in the produce of either of the other years. There is here again evidence that with favourable maturation there is low percentage of both mineral matter and nitrogen; that is, favourable maturation means the greater accumulation of non-nitrogenous organic substances—carbohydrates, and especially starch—the result necessarily being a lowering of the proportion, though not of the actual amount, of both the nitrogenous and the mineral constituents.

Turning to the composition of the ash, Table VI (p. 32) shows a considerably higher percentage of potash, and a considerably lower percentage of phosphoric acid, in the ash of the grain of the two seasons of better quality. At the same time there is a tendency to lower percentages of magnesia with the higher percentages of potash, and to higher percentages of sulphuric acid with the lower percentages of phosphoric acid, but by no means in compensating degree. The straw-ashes also show considerably higher percentages of potash, low percentages of phosphoric acid, and higher of sulphuric acid, in the better seasons. But it has before been observed that the ash of the straw, in a much greater degree than does that of the grain, contains, besides the constituents that may be essential to its own formations, a variable amount of what may be called migratory matters, the quantities of which depend on the one hand on the quantities taken up from the soil during the periods of accumulation, and on the other on the characters of the maturing period, which influence the amounts stored up in the seed.

The variations in the average percentage composition of the ash itself in the several seasons, as shown in Table VI, though instruc-

TABLE VII.

General Characters of the Produce, and Mean Quantity of Nitrogen, Ash, and each Ash-Constituent, *per* 1000 *Dry Matter of Produce*. Mean of Nine Differently Manured Plots in each Season.

Harvests.	Weight per bushel of grain, lbs.	Grain to 100 straw.	Dry matter per acre, lbs.	Per 1000 dry matter.		Ash-constituents per 1000 dry matter.					
				Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Silica.
					Grain.						
1852	56·8	46·8	1161	20·2	19·6	0·62	2·49	5·54	10·38	0·08	0·18
1856	57·4	53·9	1526	19·8	19·2	0·56	2·18	5·76	10·18	0·12	0·19
1858	61·4	66·4	1670	19·6	19·6	0·60	2·05	6·51	9·91	0·19	0·14
1863	62·6	65·8	2335	16·6	17·5	0·53	1·91	5·84	8·72	0·23	0·12
					Straw.						
1852	56·8	46·8	2467	5·9	61·0	2·98	1·02	7·45	2·06	1·49	44·2
1856	57·4	53·9	2839	3·9	52·7	2·62	0·76	7·97	1·80	1·66	36·0
1858	61·4	66·4	2550	4·6	55·9	3·05	0·92	11·54	1·70	2·71	33·1
1863	62·6	65 8	3493	3·2	56·5	3·18	0·98	10·20	1·38	1·91	36·4

tive, do not clearly indicate the variations in the mineral composition of the produce. These are best shown in Table VII (p. 34), which gives, besides the general agricultural characters of the produce as before, the average amounts for each season, of nitrogen, of total ash, and of each of the selected ash-constituents, *per* 1000 *dry matter of the produce*, grain and straw respectively:—

Thus, notwithstanding the much higher percentage of potash in the ash of the grain of the two good seasons than in that of the two bad ones, its proportion in the dry substance of the grain of the best season, 1863, is, owing to its small amount of total ash, little above that in the dry substance of the grain of the two bad seasons, with their higher amounts of total ash. The dry substance of the grain of the other good season, 1858, with its less perfect ripening, and higher proportion of total ash, shows, however, a high proportion of potash in the dry substance.

The most striking difference in the average mineral composition of the grain in the four seasons is the very much lower proportion of phosphoric acid, and with this a lower proportion of magnesia also, in the dry substance of the best matured grain—that of 1863. These are characteristics of a less proportion of bran to flour—in other words, of a greater accumulation of starch in the ripening. The variation in the mineral composition is thus coincident with, and dependent on, variation in that of the organic substance due to season.

After what has been said of the circumstances affecting the composition of the straw-ash, it is unnecessary to consider in any detail the differences in the proportion of the several mineral constituents in the dry substance of the straw in the different seasons. It may be noted, however, that, in the better seasons, the amount of potash remaining in the straw is much greater, that of phosphoric acid is less, and that of sulphuric acid greater, in proportion to a given quantity of dry substance of the straw.

The summary Table VIII (p. 36) shows the mean yield per acre of the produce, and of its constituents, on the nine differently manured plots in each of the four seasons:—

It is thus seen that under identical conditions as to manuring, there was about twice as much grain, nearly one and a half time as much straw, and more than one and a half time as much total produce, in the best as in the worst of the four seasons. Of nitrogen in the total produce, the average amount per acre was only 38 lbs. in 1852, but 50·1 lbs. in 1863; whilst of the less total amount in the crop in 1852, a considerably larger actual quantity remained in the straw. In fact, of the total nitrogen in the crop, in 1852, 38·4 per cent., in 1856, 27·1, in 1858, 26·2, and in 1863, only 22·6 per cent. remained in the straw.

TABLE VIII.

General Characters of the Produce, and Average Quantities *per Acre*, of Grain, Straw, Total Produce, Nitrogen, Ash, and of Selected Ash-Constituents, in each of the Four Seasons. Mean of Nine Differently Manured Plots in each Season.

Harvests.	Weight per bushel of grain, lbs.	Grain to 100 straw.	Produce per acre, lbs.	Per acre, lbs.		Ash-constituents per acre, lbs.					
				Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Silica.
					Grain.						
1852	56·8	46·8	1390	23·4	22·7	0·72	2·89	6·4	12·0	0·09	0·21
1856	57·4	53·9	1832	30·2	29·4	0·86	3·32	8·8	15·5	0·19	0·29
1858	61·4	66·4	1993	32·7	32·8	1·00	3·42	10·9	16·6	0·32	0·23
1863	62·6	65·8	2761	38·8	40·9	1·24	4·47	13·6	20·4	0·53	0·27
					Straw.						
1852	56·8	46·8	2967	14·6	150·6	7·34	2·52	18·4	5·1	3·68	109·1
1856	57·4	53·9	3397	11·2	149·7	7·43	2·16	22·6	5·1	4·72	102·1
1858	61·4	66·4	3003	11·6	142·5	7·77	2·35	29·4	4·3	6·92	84·4
1863	62·6	65·8	4197	11·3	197·3	11·10	3·43	35·6	4·8	6·68	127·2
					Total.						
1852	56·8	46·8	4357	38·0	173·3	8·06	5·41	24·8	17·1	3·77	109·3
1856	57·4	53·9	5229	41·4	179·1	8·29	5·48	31·4	20·6	4·91	102·4
1858	61·4	66·4	4996	44·3	175·3	8·77	5·77	40·3	20·9	7·24	84·7
1863	62·6	65·8	6958	50·1	238·2	12·34	7·90	49·2	25·2	7·21	127·5

Yet, with by far the largest amount accumulated in the grain in 1863, its percentage in it is much lower than in either of the other years. There is thus, with the best growing and maturing conditions, the largest amount of nitrogen taken up by the plant, the largest amount accumulated in the grain, and the lowest percentage of it in the grain.

Again, under equal conditions as to supply by manure, one and a third time as much of total mineral, or ash-constituents, is stored up in the total crop in the season of highest luxuriance and highest maturation, as in either of the others; whilst the percentage of ash in the dry substance of the grain is lower than in either of the other years. There is also more of each of the mineral constituents enumerated (excepting silica), taken up, with the same supply by manure, in the two better than in the two worse seasons; and comparing the best season with the worst there is about one and a half time as much lime, magnesia, and phosphoric acid, and about twice as much potash and sulphuric acid, taken up in the season of most favourable growth and maturation. Yet, as Table VII (p. 34) shows, the proportion of lime, magnesia, and phosphoric acid was lower, and that of the potash nearly as low, in the grain of the large and well-matured produce.

In these facts as to the nitrogen and the ash-constituents, there is again striking evidence of the much greater influence of season than of manuring on the composition of a ripened plant, and especially of its final product—the seed. The extent, and the limits, of the effects of manure, or of exhaustion, on the composition of wheat-grain and wheat-straw will be more clearly brought to view in the next illustrations.

In the first place, Table IX (p. 38) shows a not very wide range of difference in the weight per bushel of the grain grown under such very wide differences as to manure, but all under equal season influences. Still the differences, such as they are, are not without their significance. Without manure (Plot 3), with sluggish growth and ripening, and with ammonium-salts alone (Plot 10*a*), that is, with great mineral exhaustion, the weight per bushel is low; it is also low on Plot 11*a*, where, besides the ammonium-salts, there is superphosphate, but neither potash, soda, nor magnesia supplied. With farmyard manure (Plot 2) it is high. In the other cases—with mixed mineral manure (Plot 5*a*), the same and ammonium-salts (Plot 7*a*), ammonium-salts, superphosphate, and soda (Plot 12*a*), ammonium-salts, superphosphate, and potash (Plot 13*a*), and ammonium-salts, superphosphate, and magnesia (Plot 14*a*)—it is fairly uniform.

The percentage of nitrogen in the dry substance of the grain is fairly uniform, excepting that on Plot 5*a*, with mineral manure alone and great nitrogen exhaustion, it is low; and on Plot 10*a*, with ammonium-salts alone, and therefore great relative excess of nitrogen and deficiency of mineral constituents supplied, it is high.

TABLE IX.

General Characters of the Produce, and *Mean Percentage* of Selected Constituents *in the Pure Ash*, of the Grain and Straw, under each of the Nine Different Conditions as to Manuring. Mean Result of the Four Seasons for each Plot.

Plots.	Weight per bushel of grain, lbs.	Grain to 100 straw.	Produce per acre, lbs.	Per cent. in dry matter.		Per cent. in pure ash.					
				Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Silica.
					Grain.						
2	60·6	59·1	2348	1·80	1·96	2·57	11·8	30·0	53·2	0·51	0·72
3	58·5	62·6	1005	1·85	2·01	2·71	11·0	31·3	51·7	0·85	0·97
5*a*	59·6	65·6	1169	1·74	2·02	2·82	11·0	31·4	52·1	0·67	0·90
10*a*	58·4	61·1	1713	2·08	1·75	3·76	11·5	32·0	48·9	1·69	1·01
11*a*	59·0	61·8	2107	1·92	1·85	3·83	11·2	30·3	51·3	1·02	0·90
12*a*	60·1	59·1	2394	1·83	1·86	3·12	11·1	31·5	51·4	0·90	0·72
13*a*	60·2	57·0	2338	1·85	1·86	2·92	11·1	31·7	51·5	0·73	0·72
14*a*	60·0	56·9	2411	1·87	1·85	2·94	11·4	31·1	51·7	0·85	0·68
7*a*	59·6	54·1	2464	1·87	1·88	2·79	11·8	31·5	51·5	0·50	0·84
					Straw.						
2	60·6	59·1	3972	0·38	6·59	3·92	1·55	16·8	3·30	2·83	68·3
3	58·5	62·6	1606	0·44	6·38	4·41	2·00	13·2	3·43	3·20	71·1
5*a*	59·6	65·6	1783	0·44	6·83	3·76	1·33	14·3	3·98	4·01	69·2
10*a*	58·4	61·1	2804	0·58	5·09	6·68	1·75	14·0	2·68	4·55	66·8
11*a*	59·0	61·8	3407	0·46	5·40	6·61	1·82	9·2	3·09	3·35	72·3
12*a*	60·1	59·1	4052	0·39	5·26	5·91	1·68	16·9	2·78	3·46	65·1
13*a*	60·2	57·0	4099	0·34	5·45	4·83	1·44	20·6	2·73	3·34	62·3
14*a*	60·0	56·9	4236	0·38	5·25	5·84	1·85	18·8	2·89	3·52	63·0
7*a*	59·6	54·1	4557	0·51	5·47	5·15	1·42	19·6	3·25	3·62	62·1

The percentage of total mineral matter (pure ash), is also fairly uniform, excepting that with farmyard manure (2), with purely mineral manure (5*a*), and without manure (3), it is somewhat high; and with ammonium-salts alone (10*a*), where there is very abnormal mineral exhaustion, it is very low.

A glance at the columns showing the mean percentage of the chief constituents of the ash of the grain shows a very marked uniformity under the nine very characteristically different conditions as to actual and relative mineral supply. In the potash column, for example, the only exceptions to this general uniformity are that with farmyard manure (2), and with ammonium-salts and superphosphate, but without either potash, soda, or magnesia applied (11*a*), the mean percentage is low. In the case of the farmyard manure plot, the result is obviously due to the characters of the growth and maturation, and not to deficient supply, as confirmed by the comparatively high percentage of potash in the straw-ash. In the case of 11*a*, there is doubtless great potash exhaustion, and accordingly the straw-ash also shows a very low percentage of potash; indeed a much lower percentage than on any other plot.

In the phosphoric acid column again there is, upon the whole, great uniformity. The exceptions are, that with farmyard manure (2), the percentage is very high; and with ammonium-salts alone (10*a*), where there is very abnormal exhaustion, it is very low; and consistently with this, the percentage in the straw-ash is also low. With this low amount of phosphoric acid in the ash of both the grain and the straw of Plot 10*a*, there is, in both the grain-ash and the straw-ash of this plot, the highest percentage of sulphuric acid.

The influence of supply, or exhaustion, on the amount of produce, on the amount of the different constituents taken up by the plant, on the distribution of the constituents in the grain and straw respectively, and on the composition of the dry matter of the grain and straw, will be further illustrated in Tables X and XI (pp. 40—42). It will be convenient first to consider the variations in the amounts of produce, and in the amounts and distribution of the various constituents taken up over a given area, and afterwards the composition of the dry substance produced.

In reference to the results given in Table X (pp. 40—41), it is first to be noted that the quantity of produce, both grain and straw, yielded per acre, varied exceedingly under the very different conditions as to manuring. Without manure (3), the produce was very small; with a full mineral manure, but no nitrogen supplied (5*a*), it was but little higher. Then, taking the series with a given amount of ammonium-salts annually applied, there is in every case much more produce, and much more nitrogen and mineral matter taken up,

TABLE X.

General Characters of the Produce, and the Amounts of Nitrogen, Total Mineral Matter (Ash), and each Ash-Constituent *Per Acre*, in Grain, Straw, and Total Produce. Mean Results of the Four Seasons for each Plot.

Plots.	Weight per bushel of grain. lbs.	Grain to 100 straw.	Produce per acre, lbs.	Per acre, lbs.		Ash-constituents per acre, lbs.						
				Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Chlorine.	Silica.
						Grain.						
2	60·6	59·1	2348	35·4	38·5	0·98	4·48	11·6	20·4	0·22	0·02	0·27
3	58·5	62·6	1005	15·5	16·8	0·45	1·83	5·3	8·6	0·14	trace	0·16
5*a*	59·6	65·6	1169	17·0	19·7	0·55	2·16	6·2	10·2	0·13	trace	0·18
10*a*	58·4	61·1	1713	30·0	25·2	0·95	2·87	8·1	12·2	0·45	0·05	0·25
11*a*	59·0	61·8	2107	34·0	32·8	1·26	3·63	10·0	16·7	0·36	0·01	0·29
12*a*	60·1	59·1	2394	36·8	37·5	1·18	4·08	12·0	19·0	0·39	0·03	0·26
13*a*	60·2	57·0	2338	36·3	36·5	1·06	3·99	11·8	18·7	0·30	0·01	0·26
14*a*	60·0	56·9	2411	37·9	37·6	1·10	4·22	11·9	19·3	0·36	0·02	0·25
7*a*	59·6	54·1	2464	38·6	38·7	1·07	4·49	12·4	19·8	0·21	trace	0·32
						Straw.						
2	60·6	59·1	3972	12·8	219·3	8·59	3·39	36·9	7·2	6·17	6·89	149·9
3	58·5	62·6	1606	5·9	86·2	3·73	1·72	11·3	3·0	2·72	1·54	61·5
5*a*	59·6	65·6	1783	6·6	101·9	3·84	1·36	14·3	4·1	4·06	1·85	70·8
10*a*	58·4	61·1	2804	13·6	119·9	7·86	2·05	16·5	3·1	5·07	2·93	81·2
11*a*	59·0	61·8	3407	13·1	154·3	10·25	2·86	13·9	4·7	5·10	2·99	111·7
12*a*	60·1	59·1	4052	13·1	178·3	10·72	3·07	30·3	4·8	6·14	6·44	115·8
13*a*	60·2	57·0	4099	11·6	185·8	8·99	2·69	39·2	4·9	6·19	8·87	114·9
14*a*	60·0	56·9	4236	13·6	186·1	10·95	3·47	34·9	5·2	6·50	7·38	117·3
7*a*	59·6	54·1	4557	19·4	208·3	10·75	2·95	41·5	6·7	7·58	9·55	128·4

Total Produce (Grain and Straw).

2	60·6	59·1	6320	48·2	257·8	9·57	7·87	48·5	27·6	6·39	6·91	150·1
3	58·5	62·6	2611	21·4	103·0	4·18	3·55	16·6	11·6	2·86	1·54	61·7
5*a*	59·6	65·6	2952	23·6	121·6	4·39	3·52	20·5	14·3	4·19	1·85	71·0
10*a*	58·4	61·1	4517	43·6	145·1	8·81	4 92	24·6	15·3	5·52	2·98	81·5
11*a*	59·0	61·8	5514	47·1	187·1	11·51	6·49	23·9	21·5	5·46	3·00	112·0
12*a*	60·1	59·1	6446	49·9	215·8	11·90	7·15	42·3	23·8	6·53	6·47	116·1
13*a*	60·2	57·0	6437	47·9	222·3	10·05	6·68	51·0	23·6	6·49	8·88	115·2
14*a*	60·0	56·9	6647	51·5	223·7	12·05	7·69	46·8	24·5	6·86	7·40	117·5
7*a*	59·6	54·1	7021	58·0	247·0	11·82	7·44	53·9	26·5	7·79	9·55	128·7

TABLE XI.

General Characters of the Produce, and Amounts of Nitrogen, Total Ash, and of Selected Ash-Constituents *per* 1000 *Dry Matter of Grain, and of Straw.* Mean Results of the Four Seasons for each Plot.

Plots.	Weight per bushel of grain. lbs.	Grain to 100 straw.	Dry matter per acre, lbs.	Per 1000 dry matter.		Ash-constituents per 1000 dry matter.					
				Nitrogen.	Ash (pure).	Lime.	Magnesia.	Potash.	Phosphoric acid.	Sulphuric acid.	Silica.
					Grain.						
2	60·6	59·1	1963	18·0	19·6	0·50	2·28	5·93	10·38	0·11	0·14
3	58·5	62·6	836	18·5	20·1	0·54	2·19	6·30	10·35	0·17	0·19
5*a*	59·6	65·6	975	17·4	20·2	0·56	2·22	6·35	10·51	0·13	0·18
10*a*	58·4	61·1	1443	20·8	17 5	0·66	1·99	5·65	8·46	0·31	0·17
11*a*	59·0	61·8	1773	19·2	18·5	0·71	2·05	5·68	9·44	0·20	0·16
12*a*	60·1	59·1	2014	18·3	18·6	0·59	2·03	5·96	9·47	0·19	0·13
13*a*	60·2	57·0	1963	18·5	18·6	0·54	2·03	6·01	9·52	0·15	0·13
14*a*	60·0	56·9	2028	18 7	18·5	0·54	2·09	5·85	9·52	0·18	0·12
7*a*	59·6	54·1	2062	18·7	18·8	0·52	2·18	5·99	9·62	0·10	0·16
					Straw.						
2	60·6	59·1	3328	3 8	65·9	2·58	1·02	11·07	2·18	1·85	45·03
3	58·5	62·6	1351	4·4	63·8	2·88	1·27	8·34	2·19	2·01	45·55
5*a*	59·6	65·6	1492	4·4	68·3	2·57	0·91	9·60	2·74	2·72	47·46
10*a*	58·4	61·1	2355	5·8	50·9	3·34	0·87	6·99	1·30	2·15	34·48
11*a*	59·0	61·8	2859	4·6	54·0	3·59	1·00	4·85	1·65	1·78	39·08
12*a*	60·1	59·1	3388	3·9	52·6	3·16	0·91	8·93	1·41	1·81	34·18
13*a*	60·2	57·0	3411	3·4	54·5	2·64	0·79	11·50	1·43	1·81	33·69
14*a*	60·0	56·9	3·46	3·8	52·5	3·09	0·98	9·83	1·46	1·84	33·07
7*a*	59·6	54·1	3809	5·1	54·7	2·82	0·77	10·90	1·76	1·99	33·70

than with the mineral manure alone. In fact, there is considerably more than twice as much produce, both grain and straw, grown under the influence of ammonium-salts and the mixed mineral manure (7*a*), as with the mixed mineral manure alone (5*a*); and there is one and a half time as much with ammonium-salts and the mixed mineral manure (7*a*), as with ammonium-salts alone (10*a*).

Comparing the different members of the ammonium-salt series one with another, where the ammonium-salts are used alone (10*a*), the produce is much the lowest in amount; with superphosphate added there is more; with superphosphate and either potash, soda, or magnesia, there is more still, but almost identical amounts in the three cases; lastly, with superphosphate and potash, soda, and magnesia together, there is the highest produce among the series.

That there was so little difference in the amount of produce on the three plots, one with soda, one with potash, and one with magnesia, is explained by the fact already recorded, that the plots which received soda, or magnesia, but no potash, in 1852, and each year since, had, before that time, received potash, the effects of the residue of which were very marked for many years, and have only in recent years obviously declined. In reference to this point, it may be stated that Hermann von Liebig, having expressed a wish to examine some of the Rothamsted experimental soils, samples from some of the plots in the experimental wheat field, which had been collected in October, 1865, that is, after the removal of the twenty-second crop from the commencement, and the fourteenth since the application of the same manures year after year on the same plots, were sent to him accordingly. He determined in them the constituents soluble in dilute acetic acid, and the amount of phosphoric acid soluble in dilute nitric acid. The results showed a considerable accumulation of both potash and phosphoric acid where they had been applied in excess; and in each case the accumulation was chiefly in the first 9 inches of depth. Again, Dr. Voelcker's analyses of the drainage-waters from the same field showed comparatively little loss of either potash or phosphoric acid by drainage.

With the very great differences in the amounts of produce grown according to the manure supplied, the Table (X) shows, in the main, corresponding differences in the amounts of nitrogen, total mineral matter, and individual ash-constituents, taken up. For the sake of brevity, attention must chiefly be confined to the variations in the amounts of potash and phosphoric acid in the produce of the different plots.

Of potash, about three times as much was contained in the farmyard manure crop as in the unmanured one; and there was more than three times as much in the crops grown with ammonium-salts and

artificial mineral manure containing potash, as without manure. The quantities of potash in the produce in the other cases when ammonia was applied have an obvious connection with the supply of it. Of the total potash in the crops, only from one-fourth to one-third is accumulated in the grain, excepting in the case of Plot 11*a*, where there is great exhaustion of potash, but otherwise conditions favourable for seed-formation, and here the proportion of the total potash taken up which is accumulated in the grain is greater, and the amount remaining in the straw is proportionally less. On the other hand, the proportion so remaining is the greatest where the supply is the most liberal (2, 13*a*, and 7*a*).

Of phosphoric acid, there is only about twice as much in the highly artificial manured as in the unmanured produce. But a much larger proportion of the whole than in the case of the potash is accumulated in the grain. In fact, whilst only about one-fourth or one-third of the total potash of the crop is accumulated in the grain, about three-fourths, or even more, of the total phosphoric acid of the crop is stored in the grain.

It may be observed in passing, that only a very small proportion (about one-tenth) of the total lime of the crop is found in the seed. Of the total magnesia generally more than one-half, of the sulphuric acid a very small proportion, of the chlorine scarcely a trace, and of the silica the smallest proportion of all, is found in the grain-ash.

Bearing in mind the foregoing facts as to the very variable amounts of the different ash-constituents taken up under the very different conditions as to manuring, and as to the very different distribution of the several constituents in the grain and straw respectively, we are prepared to consider in what proportion they exist to the dry substance of the grain and straw produced, and what is the range of variation in this proportion according to the condition of supply or exhaustion on the different plots. These points are illustrated in Table XI (p. 42).

The general uniformity in the amounts of total ash, nitrogen, and each ash-constituent, in a given quantity of the dry substance of the grain grown under such very varying conditions as to supply, and with such very varying actual amounts taken up by the plant, is very striking. The exceptions to uniformity are so obviously coincident with abnormal exhaustion, or with irregularity in maturation, that the evidence is even the stronger that with equal maturation—that is with uniformity in organic composition—there would be uniformity in mineral composition also. Further, the wide differences in the amounts of the different ash-constituents per 1000 dry matter of the straw show in what variable degrees the constituents have been withdrawn from the general stores of the plant, to provide the necessary

quantities for the all but uniform requirements, for formation or reserve, of a given weight of the final product of the plant—the seed.

Referring to some of the exceptions to uniformity in mineral composition of the grain a little more in detail, it is seen that the lowest proportion of potash is in the grain of Plot 10*a* with ammonium-salts alone, and Plot 11*a* with ammonium-salts and superphosphate (without potash). In these cases, there was very abnormal exhaustion of potash; and consistently with this the proportion of potash in the straw is also very low. It may be noted that with the lower proportion of potash in the dry substance in these cases, there is a somewhat higher proportion of lime in both grain and straw. Again, the uniformity in the proportion of potash in the dry matter of the grain, with ammonium-salts, superphosphate, and soda (with residue of potash 12*a*), with ammonium-salts, superphosphate, and potash (13*a*), with ammonium-salts, superphosphate, and magnesia (with residue of potash 14*a*), with ammonium-salts, superphosphate, soda, potash, and magnesia (7*a*), and with farmyard manure (2), is very marked; whilst the differences in the amounts in the corresponding straws are not only very considerable, but have a very obvious connection with the supply by manure.

The most prominent exceptions to uniformity in the proportion of phosphoric acid in the dry substance of the grain is in the case of Plot 10*a*, with ammonium-salts alone. Here there is very abnormal exhaustion of phosphoric acid, the proportion in the dry substance of the grain is very low, and it is also the lowest in the dry substance of the straw. With the lower proportion of phosphoric acid in the dry substance of the grain in this case, there is the highest proportion of sulphuric acid, but the excess is not at all in equivalent amount.

Thus far it has been sought to elicit the teachings of this second series of wheat grain and straw-ash analyses, by reference to two sets of summary tables; one showing the mean results of the nine plots, for each of the four years, and the other the mean results over the four years, for each of the nine differently manured plots separately. It will be well now to direct attention briefly to the results as given in more detail in the Appendix Tables, X, XI, and XII, in order to ascertain how far such examination leads to accordant conclusions, or brings to view points of interest or importance that would otherwise be overlooked.

The Appendix Table X shows, for each of the nine plots separately, the percentage composition of the ash (of grain and straw) in each of the four years; the first two of which were unfavourable, and the last two favourable for the crop, especially the last of the four. The four seasons were, the first, fifth, seventh, and twelfth, of a series of 12 years. It should be further observed, that after the third of the

four selected years, the supply of potash on the three plots annually receiving it (5*a*, 13*a*, and 7*a*) was reduced to two-thirds the previous amount.

On examination of the table, it is seen that with every condition as to manuring without exception, whether involving an excessive supply or an exhaustion of potash, the percentage of potash in the grain-ash is higher in the two later and better seasons, than in the two earlier but inferior ones. In the straw-ashes again there is, with very different actual percentages in the case of the different plots, uniformly an increase in the percentage of potash in the ash from the first to the third of the four years, and with one exception some decline in the fourth year. The exception is on Plot 7*a*, where, besides ammonium-salts and superphosphate, there is annually applied a considerable excess of potash, soda, and magnesia, salts; but where, as above stated, the amount of potash supplied had then been reduced for several years, notwithstanding which the percentage of potash in the straw-ash is increased. The decline in the percentage of potash in the straw-ash in the fourth and best year of the series in the other cases, is doubtless in great measure explained by the fact, to which attention has already been called, namely, that owing to favourable seed-forming and maturing conditions supervening on great luxuriance, and therefore great accumulation by the plant, its stores were very largely drawn upon in the production of a very unusually large amount of grain.

The details further show that with the uniform increase in the percentage of potash in the grain-ash in the two later and better seasons, there is at any rate a distinct tendency to a reduction in the percentage of magnesia; but not in compensating degree.

Almost equally as marked as the increase in the percentage of potash in the grain-ash, in the later and better years, is the decline in the percentage of phosphoric acid in those years. And as the increase in the percentage of potash in the ash was manifest in the better years even under conditions of exhaustion of it, so here the decline in the percentage of phosphoric acid in the grain-ash in the better years occurs even where there was a liberal annual application of it by manure. The greatest decline is, however, on Plot 10*a*, manured annually with ammonium-salts alone, and where, therefore, there is very abnormal exhaustion of phosphoric acid. Again, with the general decline in the percentage of phosphoric acid in the grain-ash in the later and better years, there is also a general decline in its percentage in the straw-ash in those years, and especially in the last and best year, even where the supply by manure was liberal.

With the general decrease in the percentage of phosphoric acid in both the grain and the straw-ashes in the later years, there is also a

very general, but not uniform increase in the percentage of sulphuric acid. This increase in the percentage of sulphuric acid in the later years is, however, more marked in the straw than in the grain-ashes. Of chlorine, whether the grain itself contained it in any quantity or not, there is scarcely a trace in the grain-ashes. But in the straw-ashes, the percentage is uniformly higher, and sometimes very much higher, in the later and better years. In fact, the increase in the percentage of chlorine in the straw-ashes is more marked than is that of the sulphuric acid.

Whatever may be the case with the sulphuric acid (or its sulphur) there is no evidence leading to the conclusion that chlorine is an essential constituent of the ripened grain; but the question obviously suggests itself, how far the small but variable amounts of sulphuric acid, and the almost total absence of chlorine, in the grain-ashes, have a physiological significance; or whether they are not in a greater or less degree dependent on the conditions of the incineration in the presence of phosphoric acid with less than three of fixed base. Again, there is the question how far the larger and variable amounts of both sulphuric acid and chlorine in the straw-ashes, in a sense compensate the deficiency of phosphoric acid; or how far, having been taken up by the plant, or the sulphuric acid partly due to oxidation of sulphur in the burning, they remain in the ash, containing as it does so little phosphoric acid in proportion to the fixed bases present, though at the same time so much silica. There is in fact a very considerable amount of both sulphuric acid and chlorine in the straw-ashes, notwithstanding the large amount of silica they contain; but it is at the same time to be noted that, as a rule, the relatively high percentages of sulphuric acid and chlorine are in years when the percentage of silica is relatively low.

The influence of the variations in the percentage composition of the ashes on the mineral composition of the dry matter of the produce in the different seasons, is best studied in the Appendix Table XI, in which is shown the amount of each constituent per 1000 of dry matter, grain and straw respectively, in each of the four seasons, under each of the nine different conditions as to manuring.

In discussing the first series of ash-analyses, which related to the produce of three very differently manured plots, in sixteen consecutive seasons, it was seen how small was the variation in the mineral composition of the grain due to manuring, compared with that due to season, that is, to differences in the conditions of seed-formation and maturation. Again, the consideration of the mean results of the nine different conditions as to manuring, in each of the four years (Table VII, p. 34), and of the mean results over the four years, for each of the nine differently manured plots (Table X, pp. 40—41),

showed (10*a* excepted) more variation in the composition of the grain according to season than according to manure.

Quite consistently, the details given in Appendix Table XI. show, under each of the nine conditions as to manuring, a notable difference in the mineral composition of the grain grown in the four different seasons, with their very different seed-forming and maturing conditions, and the very different characters of the grain accordingly. Owing, however, to the different proportions of total ash under these circumstances, and to the generally relatively small amount in the grain of 1863, the differences in the mineral composition of the dry substance of the grain in the different years are by no means so great as might be anticipated from the more marked differences in the percentage composition of the ash itself. Nevertheless, the amount of potash per 1000 dry substance of the grain is, with every condition as to manuring without exception, higher in the favourable season 1858, and almost without exception in the extraordinarily favourable season 1863, than in the two unfavourable seasons. On the other hand, the amount of phosphoric acid per 1000 dry matter, is in 1858 almost without exception, and in 1863 without exception, lower than in the two unfavourable seasons. In the season of 1863, with both very large quantity and very high quality of grain, the proportion of phosphoric acid is indeed very low; and the potash is much lower than in 1858, owing, doubtless, as before explained, to the very favourable seed-forming and maturing tendency, and the consequent great development of organic substance (chiefly starch) in relation to the mineral matter stored up in the grain.

Thus, the results of Series 1, with three very different conditions as to manuring, each over sixteen consecutive seasons, and those of Series 2, relating to nine different conditions as to manuring, each in four very different seasons, consistently show that, under otherwise equal circumstances, the mineral composition of wheat-grain, excepting in cases of very abnormal exhaustion, is very little affected by different conditions as to manuring, provided only that the grain is well and normally ripened. Again, the results consistently show that the composition may vary very greatly with variations of season, that is with variations in the conditions of seed-formation and maturation, upon which the organic composition of the grain depends. In other words, differences in the mineral composition of the ripened grain are associated with differences in its organic composition.

Third Series of Analyses.

In considering the results of the first and second series of ash-analyses, some illustrations of the effects of supply, or exhaustion, have

been given. But as the first series, though relating to the produce of sixteen consecutive seasons, included the results for only three different conditions of manuring, and as the second series, though relating to nine different conditions as to manuring, included results for only four, and those not consecutive seasons, the evidence afforded was in either case somewhat limited. The third series, now to be discussed, was arranged with more special reference to the question of the effects of continuous liberal supply, or of exhaustion, of constituents, both on the quantity and the composition of the produce.

This third series of ash-analyses relates to the produce obtained over a period of twenty consecutive years, 1852—1871 inclusive, on ten differently manured plots, in the experimental wheat field which has now grown the crop every year, commencing 1844, up to the present time. Most of the plots in the field consist of two lands, designated *a* and *b* respectively. Prior to 1852, but especially for the crops of 1846 and 1848, the *a* and the *b* portions were manured somewhat differently, but from 1852 to 1863 inclusive they were manured alike. It will be observed (see p. 29) that in seven out of the nine conditions of manuring to which the second series of analyses relates, the produce was from the *a* portions of the plots; the remaining two not being divided plots. Of the ten plots, the results relating to which are now to be considered, nine are substantially the same as those to which Series 2 relates. Two (2 and 3) are in fact absolutely the same, and the other seven are the duplicate or *b* portions of the plots which, during the whole of the twenty years with which we are now concerned, were manured precisely as described for the *a* portions at p. 29.

The tenth plot now included is 10*b*, which also during the period under consideration, was manured precisely as 10*a*, that is, it receives ammonium-salts alone, and in the same quantities every year. Prior to 1852, however, 10*b* was once (in 1846) unmanured when 10*a* received ammonium-salts; once (1848) 10*b* received a mineral manure comprising potash, soda, magnesia, and superphosphate of lime, as well as ammonium-salts, when 10*a* received ammonium-salts alone; and once (1850) 10*b* received the same mineral manure alone, when 10*a* received ammonium-salts alone. Thus, during the years prior to the period now in question, Plot 10*b* twice received no ammonium-salts when they were supplied to Plot 10*a*, and twice received mineral manure when 10*a* did not. It is of much interest, therefore, to ascertain whether there is any difference of result comparing the one plot with the other, due, on the one hand to less mineral exhaustion on 10*b*, owing to less ammonia having been previously applied, and on the other to mineral manure having been twice directly applied; whether in fact any residue of the mineral manure

twice previously applied remained in the soil, and in a condition available for succeeding crops.

Referring to the footnote at page 29, for details as to quantities, &c., the general description of the manuring of the ten plots is given on the left hand of Table XIII, page 52. The farmyard manure plot, and the unmanured plot, have respectively been under the same treatment every year, from the commencement of the experiments in 1843–4, and each of the other plots from 1851–2.

From the produce of each of the ten plots, ashes were prepared representing the grain and the straw separately, of the ten years 1852–1861, and again of the ten years 1862–1871. It is to be regretted that similar results are not available for a third period of ten years, to 1881 inclusive. The plan adopted was to take, for each of the ten years, an amount of grain proportional to the amount of produce, mix the whole, and prepare the ash from the mixture. For example, supposing the produce in one year were 1000 lbs. of grain per acre, in the next year 1500 lbs., in the next 2000 lbs., and so on, then 1000, 1500, and 2000 parts were taken, and so on, and mixed together. The straw ashes were in like manner prepared from proportional mixtures of the produce of straw.

In the Appendix Table XIII, will be found in detail the percentage composition of the ashes of the grain and straw respectively; in the Appendix Table XIV, the results calculated per 1000 dry matter of the produce (grain and straw); and in Appendix Table XV the results are calculated per acre.

It is obvious that before we can form a trustworthy judgment how far any differences in the composition of the ash, in that of the dry substance of the produce, or in the yield of individual constituents per acre, over the two periods, are due to supply or exhaustion, we must decide whether the first ten or the second ten seasons were the most favourable for the crop, so as to discriminate as far as possible between results due merely to season, and those due to manuring. The following Table, XII, which gives the mean results for the ten plots, over the first and second ten years, as to general characters of the produce, and the yield per acre, of grain, straw, and total produce, of nitrogen, total mineral matter, and of each ash-constituent, will throw light on the characters of the two periods.

It is seen that the second period, though yielding less straw, and less total produce, characters which indicate less luxuriance, that is, less accumulation during the vegetative stages of the development of the plant, nevertheless gives more grain, a higher proportion of grain to straw, and a higher weight per bushel of grain. In fact, whilst in the country at large only three of the first ten years gave more than average produce of grain, six of the second ten gave over average;

TABLE XII.

General Characters of the Produce, and *Quantities per Acre, lbs.* Mean Results for the Ten Plots over each Period.

	Grain.		Straw.		Total produce.	
	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.
Grain to 100 straw	54·5	69·7	—	—	—	—
Weight per bushel of grain	lbs. 57·1	lbs. 60·2	lbs. —	lbs. —	lbs. —	lbs. —
Produce	1740	1833	3192	2878	4932	4711
Nitrogen	29·8	28·0	14·3	11·5	44·1	39·5
Ash (pure)	28·9	28·9	148·7	134·6	177·6	163·5
Lime	0·88	0·98	7·64	8·49	8·52	9·47
Magnesia	3·07	3·10	2·18	2·49	5·25	5·59
Potash	9·47	9·57	29·93	25·35	39·40	34·92
Soda	0·06	0·05	0·61	0·83	0·67	0·88
Phosphoric acid	14·68	14·38	4·69	4·28	19·37	18·66
Sulphuric acid	0·35	0·45	6·47	5·46	6·82	5·91
Chlorine	0·02	0·03	5·23	5·27	5·25	5·30
Silica	0·22	0·17	92·26	83·05	92·48	83·22

and whilst the first ten years gave on the whole less than average produce of grain, the second ten gave more than average.

It is clear, therefore, that the first ten years were on the average more favourable for luxuriance, that is, for total accumulation by the plant, but that the second ten were more favourable for seed-formation and maturation.

Accordingly, the table shows that, taking the average of all the plots, there was rather more nitrogen, and more total mineral matter, in the total produce (grain and straw) over the first than over the second ten years; and so far as the individual mineral constituents are concerned, there was, on the average, more potash, phosphoric acid, sulphuric acid, and silica, but less lime, magnesia, soda, and chlorine, taken up and retained in the crops over the first ten years. There was, however, with the more favourable seed-forming tendencies in the second ten years, with the less amount of total mineral constituents taken up by the plant, as much or more of almost every individual mineral constituent accumulated in the grain. The only exception to this of any significance is that there was slightly less phosphoric acid in both grain and straw in the second ten years.

These facts as to the characteristic season effects of the two periods

on the accumulation of constituents by the plant, and on the distribution of them in grain and straw respectively, must obviously be borne in mind in comparing the results obtained over the two periods on the differently manured plots.

It will be convenient first to examine the evidence of effect of liberal

TABLE XIII.

General Characters of the Produce, and *Quantities per Acre*, on

Plots.	Description of manuring.	Weight per bushel of grain, lbs.		Grain to 100 straw.		Produce per acre, lbs.		
						Grain.		Straw.
		10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.
2.....	Farmyard manure.....	58·8	61·3	56·5	62·7	2145	2385	3795
3	Unmanured.....	55·8	59·4	56·8	71·0	944	881	1663
5b	Superphosphate and sulph., potash soda and magn.	57·2	60·5	59·2	67·9	1163	1007	1963
10a	Ammonium salts alone ...	55·1	59·1	52·4	66·3	1318	1553	2516
10b	Ammonium salts alone ...	56·3	59·6	53·2	66·5	1586	1707	2984
11b	Ammonium salts and superphoshate	55·9	58·9	55·5	64·5	1782	1799	3209
12b	Ammonium salts, superphosphate, and soda sulphate	58·0	60·4	54·5	63·3	2101	2173	3857
13b	Ammonium salts, superphosphate, and potash sulphate	58·3	61·2	53·9	59·9	2098	2305	3893
14b	Ammonium salts, superphosphate, and magnesia sulphate.....	58·0	60·6	53·4	64·5	2101	2210	3937
7b	Ammonium salts, superphosphate, and sulph. pot. soda, and magna. ...	57·8	60·7	52·7	59·9	2163	2309	4104
	Direct means	57·1	60·2	54·5	63·7	1740	1833	3192

supply, or exhaustion, of constituents on the different plots, by reference to the difference in the amounts of them taken up and retained per acre, over the two periods; and afterwards to consider the influence of supply or exhaustion as so determined, on the composition of the ash, and on the mineral composition of the dry substance of the produce, grain and straw.

Table XIII records the general characters of the produce of each separate plot, both as to quantity and quality, over each of the ten-year periods.

The Table (XIII) shows that, as when taking the average of the ten plots (Table XII), so under each of the ten different conditions as to manuring, there was a considerably higher proportion of grain to straw, and a considerably higher weight per bushel of the grain, over the second period. On the other hand, in every case (excepting with

farmyard manure, when the quantities were practically equal), there was less produce of straw over the second ten years; and the deficiency is obviously proportionally the greater the more defective the supply by manure. Owing, however, to the much more favourable seed-forming characters over the second period, there is in every case,

TABLE XIII.

each of the Ten Plots, over each of the Two Ten-year Periods.

Produce per acre, lbs.			Nitrogen per acre, lbs.						Plots.
Straw.	Total.		Grain.		Straw.		Total.		
10 years, 1852–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
3903	5940	6188	36·9	36·9	15·9	13·8	52·8	50·7	2
1241	2607	2122	15·6	12·6	7·5	4·9	23·1	17·5	3
1453	3126	2490	19·0	14·5	9·7	5·5	28·7	20·0	5b
2341	3834	3894	22·9	25·1	12·3	10·9	35·2	36·0	10a
2565	4570	4272	27·5	26·5	14·0	12·1	41·5	38·6	10b
2790	4991	4589	31·0	28·1	15·4	13·6	46·4	41·7	11b
3431	5958	5604	35·8	33·3	15·8	12·1	51·6	45·4	12b
3848	5991	6153	35·1	34·0	15·9	15·5	51·0	49·5	13b
3425	6038	5635	36·1	32·8	17·5	13·2	53·6	46·0	14b
3857	6267	6166	38·1	36·1	19·2	13·9	57·3	50·0	7b
2678	4932	4711	29·8	28·0	14·3	11·5	44·1	39·5	Means.

excepting without manure, and with mineral manure alone—that is, with relative deficiency of available nitrogen—a larger quantity of grain over the later period. In fact, there was more grain over the second period than over the first, wherever there was a liberal supply of ammonium-salts. It was so even where these were applied alone every year of the twenty, and for a greater or less period previously, as on Plots 10*a* and 10*b*, and where therefore there was great mineral exhaustion. Notwithstanding the generally higher produce of grain over the second period, there was, with the less growth of straw, very generally less total produce (grain and straw together) over the second period. The exceptions to this are that, with farmyard manure (2), and with ammonium-salts, superphosphate, and potash, every year (13*b*), there is some little excess over the later years. There is also slight excess, but on a much lower level of actual

produce, even on 10*a*, the most mineral exhausted plot of all, but where there was relatively very full supply of nitrogen by manure.

It is, however, only when we compare plot with plot as to amount of produce that the effects of supply or exhaustion of mineral constituents are clearly indicated. These are best brought out by a comparison of the produce on the plots each of which receives an equal amount of ammonium-salts every year, but under very different conditions as to mineral supply. Thus, with one exception only in the first period, and without exception in the second period, there is marked increase in total produce, the more liberal the supply of phosphoric acid and potash; and there is in each period more than one and a half time as much produce with ammonium-salts, superphosphate, and potash supply (13*b* and 7*b*) as with ammonium-salts alone (10*a*).

Going a little more into detail, there is more produce on 10*b* with ammonium-salts and a residue from previous application of superphosphate and potash, than on 10*a* without such residue; there is more when superphosphate is annually applied afresh (11*b*); there is again more with the further addition of a soda salt (12*b*), or a magnesia salt (Plot 14*b*), with in both cases a considerable residue of potash from previous applications (see p. 43); there is more still with the annual addition of potash (13*b*); and lastly, there is the highest produce in the series on Plot 7*b*, where, besides the ammonium-salts and superphosphate, there is an annual application of potash, soda, and magnesia salts.

Thus there is, with an equal amount of ammonium-salts in each case, a considerable increase by the addition of superphosphate, and a further increase according to the supply of potash. The amounts of produce, therefore, afford clear evidence of the relative exhaustion of available phosphoric acid and potash on some plots, and of the effects of their supply on others. A consideration of the amounts of produce over the second period compared with the first, further illustrates the relative exhaustion of potash on the different plots. Thus on Plots 10*b*, 11*b*, 12*b*, and 14*b*, where there is no annual supply of potash, and the residue from previous applications becomes more and more exhausted, there is notably less produce over the second period; but there is more, or nearly equal produce over the two periods on Plots 13*b* and 7*b*, where the supply of potash is kept up.

The columns showing the average amounts of nitrogen yielded per acre per annum in the produce over the two periods show, with equal amounts supplied by manure, very different amounts taken up and retained on the different plots with their different mineral supplies; there being much more so taken up and retained where there was no deficiency of phosphoric acid or of potash.

We now turn from these general indications of the effects of supply or exhaustion of mineral constituents, to the evidence afforded by the amounts of these in the produce of the different plots, and over the two periods. Table XIV (pp. 56–57) supplies copious illustrations on these points.

Little need be said as to the results relating to Plot 2 with farmyard manure, Plot 3, without manure, and Plot 5*b*, with a complete mineral manure (including phosphoric acid and potash), but without nitrogenous supply. With farmyard manure there is the most, without manure the least, and with the complete mineral manure without nitrogen not much more, total mineral matter stored up in the crop. The details show, however, that the excess of ash-constituents in the crop of the farmyard manure plot is chiefly in silica, but in some degree in phosphoric acid; whilst there is more of every other constituent, potash included, in the produce of one or more of the artificially manured plots.

The most instructive comparison is that between the plots receiving the same amounts of ammonium-salts, with different conditions as to mineral supply by manure. Confining attention first to the amounts of ash-constituents *in the total produce*, it is seen that over the first ten years the quantity increases on the plots in question in the following order: 10*a*, 10*b*, 11*b*, 12*b*, 13*b*, 14*b*, 7*b*, that is, almost exactly in the order of supply by manure, especially of potash. The exception is, that Plot 14*b* without direct potash supply during the period under consideration, but with considerable residue from previous applications, gives, over the first period, slightly more total ash than 13*b* with its annual fresh supply of potash. Over the second period, however, when the residue of potash from previous applications to Plots 12*b* and 14*b* becomes more exhausted, 13*b* with its annual supply yields much more than either. Again, whilst there is considerably less mineral matter taken up over the second period compared with the first on these two plots, there is no reduction in the amount on Plot 13*b* with its constant supply.

There is in fact, whether we compare plot with plot, or period with period, distinct evidence of the influence of supply or exhaustion on the total amount of mineral constituents taken up and retained by the plant.

Referring to the total amounts of individual mineral, or ash-constituents, taken up, the columns relating to potash more clearly indicate the comparative condition of the plots as to the available supply of it. Over the first ten years there was more taken up on 10*b*, with its residue, than on 10*a* without it; there is not quite so much taken up on 11*b*, with superphosphate, as on 10*b*, doubtless owing to greater exhaustion previous to the period under consideration; there is more on Plots 12*b* and 14*b* with their greater previous residue;

and considerably more still on Plots 13*b* and 7*b* with their annual supply. The results relating to the second period illustrate the different condition of the plots still more strikingly. There is, with the increasing exhaustion of it, less potash taken up over the second period than over the first on Plots 10*a*, 10*b*, and 11*b*. But the most instructive comparison is between Plots 12*b*, 13*b*, and 14*b*. On

Table XIV.

Average Amounts, *per Acre per Annum*, in lbs., of Total Mineral Matter (Pure of each Plot, over each of

Plots.	Ash (pure).		Ferric oxide.		Lime.		Magnesia.		Potash.	
	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.
					Grain.					
2	37·1	38·5	0·20	0·18	0·93	1·00	4·05	4·23	11·8	12·4
3	16·4	14·9	0·12	0·09	0·51	0·48	1·72	1·56	5·5	4·9
5*b*	20·4	17·3	0·13	0·09	0·54	0·49	2·15	1·84	6·6	5·7
10*a*	20·8	22·7	0·16	0·14	0·81	0·99	2·17	2·47	7·1	7·7
10*b*	25·1	25·5	0·17	0·15	0·85	1·06	2·65	2·77	8·5	8·7
11*b*	29·3	27·4	0·18	0·13	1·13	1·18	3·09	2·90	9·3	8·8
12*b*	34·7	34·0	0·19	0·18	1·03	1·22	3·67	3·61	11·4	11·4
13*b*	34·4	36·3	0·23	0·22	0·99	1·07	3·62	3·83	11·3	12·2
14*b*	34·7	35·0	0·25	0·19	1·00	1·20	3·71	3·83	11·3	11·6
7*b*	36·2	36·9	0·26	0·21	1·01	1·09	3·84	3·96	11·9	12·3
Mean	28·9	28·9	0·19	0·16	0·88	0·98	3·07	3·10	9·5	9·6
					Straw.					
2	205·4	209·5	0·91	0·60	8·14	8·90	2·59	3·03	40·8	41·1
3	84·8	70·0	0·62	0·45	4·27	3·58	1·27	1·09	13·5	10·4
5*b*	106·4	86·2	0·79	0·57	4·26	3·62	1·34	1·24	20·0	15·4
10*a*	111·5	108·1	0·71	0·45	6·62	8·00	1·81	2·19	20·2	15·4
10*b*	127·7	110·2	1·07	0·47	7·56	8·84	2·11	2·47	24·8	16·3
11*b*	146·0	122·5	0·84	0·56	8·68	10·49	2·36	2·78	21·6	17·2
12*b*	169·4	153·7	0·88	0·60	8·95	11·17	2·48	2·97	34·0	26·4
13*b*	173·6	172·1	0·86	0·55	9·07	10·18	2·41	2·86	41·9	43·0
14*b*	175·6	148·3	0·85	0·60	9·25	10·24	2·73	3·24	38·5	27·5
7*b*	186·5	165·3	1·04	0·56	9·62	9·92	2·71	3·03	44·1	40·7
Mean	148·7	134·6	0·86	0·54	7·64	8·49	2·18	2·49	29·9	25·3
					Total Produce.					
2	242·5	248·0	1·11	0·78	9·07	9·90	6·64	7·26	52·6	53·5
3	101·2	84·9	0·74	0·54	4·78	4·06	2·99	2·65	19·0	15·3
5*b*	126·8	103·5	0·92	0·66	4·80	4·11	3·49	3·08	26·6	21·1
10*a*	132·3	130·8	0·87	0·59	7·43	8·99	3·98	4·66	27·3	23·1
10*b*	152·8	135·7	1·24	0·62	8·41	9·90	4·76	5·24	33·3	25·0
11*b*	175·3	149·9	1·02	0·69	9·81	11·67	5·45	5·68	30·9	26·0
12*b*	204·1	187·7	1·07	0·78	9·98	12·39	6·15	6·58	45·4	37·8
13*b*	208·0	208·4	1·09	0·77	10·06	11·25	6·03	6·69	53·2	55·2
14*b*	210·3	183·3	1·10	0·79	10·25	11·44	6·44	7·07	49·8	39·1
7*b*	222·7	202·2	1·30	0·77	10·63	11·01	6·55	6·99	56·0	53·0
Mean	177·6	163·5	1·05	0·70	8·52	9·47	5·25	5·59	39·4	34·9

Plots 12*b* and 14*b*, with their rapidly reducing available residue of potash from previous applications, there is a great reduction in the amount taken up over the second period compared with the first, whereas on Plot 13*b*, with its liberal annual supply, there is even more taken up over the second period, though it was one of less general luxuriance. There is in fact over the first period about twice,

TABLE XIV.

Ash), and of each Ash-Constituent, in the Grain, Straw, and Total Produce, the Two Ten-year Periods.

Soda.		Phosphoric acid.		Sulphuric acid.		Chlorine.		Silica.		Plots.
10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
Grain.										
0·08	0·06	19·6	20·1	0·20	0·34	trace	0·01	0·3	0·2	2
0·04	0·02	8·2	7·5	0·23	0·22	trace	0·01	0·1	0·1	3
0·05	0·02	10·5	8·8	0·17	0·30	trace	trace	0·2	0·1	5*b*
0·04	0·05	9·6	10·4	0·59	0·69	0·12	0·10	0·2	0·1	10*a*
0·06	0·04	12·2	12·0	0·42	0·58	0·04	0·07	0·2	0·2	10*b*
0·03	0·07	14·9	13·6	0·46	0·53	trace	0·05	0·2	0·2	11*b*
0·07	0·07	17·7	17·0	0·47	0·40	trace	trace	0·2	0·2	12*b*
0·04	0·05	17·7	18·2	0·25	0·52	trace	trace	0·2	0·2	13*b*
0·06	0·04	17·9	17·6	0·26	0·35	trace	trace	0·2	0·2	14*b*
0·08	0·04	18·4	18·5	0·42	0·54	trace	trace	0·2	0·2	7*b*
0·06	0·05	14·7	14·4	0·35	0·45	0·02	0·03	0·2	0·2	Mean.
Straw.										
0·23	0·32	6·9	7·2	6·99	6·14	6·78	7·25	133·6	136·6	2
0·27	0·14	2·6	2·2	3·48	2·50	1·71	1·57	57·5	48·5	3
0·15	0·18	4·2	3·5	4·59	4·05	2·59	2·12	69·1	56·0	5*b*
0·25	0·91	3·4	3·0	5·62	5·26	3·20	2·69	69·7	70·8	10*a*
0·74	1·21	3·8	2·8	5·85	4·84	4·06	3·63	78·7	70·4	10*b*
1·54	2·40	4·9	4·4	6·34	5·67	3·59	4·60	96·9	75·3	11*b*
0·90	1·70	5·5	4·8	7·54	6·26	6·05	5·74	104·4	95·3	12*b*
0·36	0·11	5·2	5·1	7·89	6·68	8·27	9·81	99·6	96·0	13*b*
0·36	1·07	5·0	4·8	8·08	6·17	7·54	6·00	104·8	90·0	14*b*
0·42	0·27	5·4	4·9	8·35	7·07	8·52	9·33	108·3	91·6	7*b*
0·61	0·83	4·7	4·3	6·47	5·46	5·23	5·27	92·3	83·0	Mean.
Total Produce.										
0·31	0·38	26·5	27·3	7·19	6·48	6·78	7·26	133·9	136·8	2
0·31	0·16	10·8	9·7	3·71	2·72	1·71	1·58	57·6	48·6	3
0·20	0·20	14·7	12·3	4·76	4·35	2·59	2·12	69·3	56·1	5*b*
0·99	0·96	13·0	13·4	6·21	5·95	3·32	2·79	69·9	70·9	10*a*
0·80	1·25	16·0	14·8	6·27	5·42	4·10	3·70	78·9	70·6	10*b*
1·57	2·47	19·8	18·0	6·80	6·20	3·59	4·65	97·1	75·5	11*b*
0·97	1·77	23·2	21·8	8·01	6·66	6·05	5·74	104·6	95·5	12*b*
0·40	0·16	22·9	23·3	8·14	7·20	8·27	9·81	99·8	96·2	13*b*
0·62	1·11	22·9	22·4	8·34	6·52	7·54	6·00	105·0	90·2	14*b*
0·50	0·31	23·8	23·4	8·77	7·61	8·52	9·33	108·5	91·8	7*b*
0·67	0·88	19·4	18·7	6·82	5·91	5·25	5·30	92·5	83·2	Mean.

and over the second period with the declining amount where it was not applied, about two and a half times as much potash accumulated in the total crop (grain and straw), where it was liberally supplied as where it was the most exhausted (10*a*), the supply of nitrogen being equal in the two cases.

It may be noted that throughout the ammonium-salt series there is rather more of both lime and magnesia taken up over the second period than the first; and the excess, especially of lime, is generally the greater where there is the more evidence of exhaustion of potash.

Comparing plot with plot in the ammonium-salt series, the amount of phosphoric acid taken up, though obviously not independent of supply by manure, varies considerably with equal supply of it; and the variations, especially over the second period, are obviously in some degree connected with the potash supply, and the variations in growth dependent thereon.

Further examination of the Table (XIV) will show that, comparing plot with plot, the amounts of potash accumulated in the grain show a less, and those remaining in the straw a greater range of variation, according to supply, than do the total amounts accumulated in the crop. In other words, by the exigencies of grain-formation, the stores of the entire plant have yielded up to the grain a much larger proportion of the total amount taken up in some cases than in others. For example, over the first period the amounts of potash in the total produce of plots 12*b*, 13*b*, and 14*b*, are respectively, 45·4, 53·2, and 49·8 lbs. per acre, whilst the amounts in the grain are 11·4, 11·3, and 11·3 lbs., and those remaining in the straw are 34·0, 41·9, and 38·5 lbs. Over the second period, the point is still more clearly illustrated. Thus, the amounts of potash in the total produce of the three plots were: 37·8, 55·2, and 39·1 lbs.; the amounts in the grain were 11·4, 12·2, and 11·6 lbs., and in the straw they were 26·4, 43·0, and 27·5 lbs. It is obvious that the amounts taken up on 13*b*, with the annual supply, were in excess of those required for the grain-formation of the seasons in question.

Upon the whole, the evidence is quite distinct that the amounts of mineral constituents found in the total crop on the different plots were very directly influenced by their supply or exhaustion within the soil. It is also clear that, even under equal conditions as to supply of nitrogen, characters of season, and other circumstances, the final distribution of the mineral constituents in the grain and straw respectively is not in proportion to the amount in the total plant, but is materially influenced by the seed-forming characteristics of the seasons; the amount accumulated in the grain being fairly equal with very different amounts stored in the total plant, provided this supply be not below a certain limit.

It is then established, that the amounts of the mineral or ash-constituents found in the total crop, have a very direct connection with the amounts available within the soil; but that the amounts stored up in the grain are little influenced by the quantity taken up, provided this is not deficient. It is in fact proved that the conditions of the experiments were such as to supply the data necessary for the elucidation of the questions with a view to the solution of which they were selected, and the analyses executed. We are now prepared to consider the influence of supply, or exhaustion, on the percentage composition of the ash, of the grain, and of the straw, and on the relation of the mineral constituents to the dry substance of the produce.

Table XV (pp. 60–61) shows the percentage of nitrogen, and of total mineral matter (pure ash), in the dry substance of the grain, and of the straw, of each plot, over each of the two periods. It also shows the percentage composition of the ash in each case.

Attention has already been called to the facts that, taking the mean of all the plots, there was a lower percentage of total mineral matter in the dry substance of the grain over the second period with its higher seed-forming, and better maturing characters; and that, with the lower proportion of total ash in the grain of the better quality, there was nevertheless a somewhat higher percentage of potash and lime, a lower percentage of phosphoric acid and silica, and with this a higher percentage of sulphuric acid, in the ash.

Turning to the potash columns in Table XV, the details show a higher percentage in the ash over the second period than over the first, under each of the very different conditions as to manure, with the single exception of the unmanured plot (3). It is also seen within what comparatively narrow limits the percentage of potash in the grain-ash varies under such very widely different conditions as to supply of it within the soil. Its percentage in the straw-ashes, on the other hand, varies very much more. Thus, in the grain-ashes the percentage of potash varies in the first period from 31·7 to 34·0, and in the second period, with its better maturing conditions, from 32·1 to 34·1; whilst in the corresponding straw-ashes it varies in the first period from 14·8 to 24·1, and in the second period from 14·1 to 25·0.

Although the percentage of potash in the grain-ashes is thus comparatively uniform, the variations, comparing plot with plot, are nevertheless consistent with the variations in the conditions of the different plots. Thus, comparing the results for the four plots each with ammonium-salts and superphosphate, one with soda (12*b*), one with potash (13*b*), one with magnesia (14*b*), and one with potash, soda, and magnesia (7*b*), in addition, the percentages of potash in the grain-ashes are, over the first period, 32·8, 32·9, 32·6, and 32·9; that

TABLE XV.

Percentage of Nitrogen, and Total Mineral Matter (Pure Ash), in the Dry Sub-
the Percentage of each Con-

Plots.	Nitrogen.		Ash (pure).		Ferric oxide.		Lime.		Magnesia.		Potash.
	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-61.	10 years, 1862-'71.	10 years, 1852-'61.
					Grain.						
2.....	2·05	1·84	2·06	1·92	0·53	0·45	2·49	2·59	10·9	11·0	31·7
3.....	1·98	1·70	2·08	2·00	0·72	0·57	3·13	3·22	10·4	10·5	33·5
5*b* ...	1·95	1·71	2·10	2·03	0·63	0·52	2·66	2·82	10·5	10·7	32·3
10*a* ...	2·07	1·90	1·88	1·72	0·73	0·61	3·90	4·35	10·4	10·9	34·0
10*b* ...	2·07	1·82	1·88	1·75	0·67	0·56	3·41	4·17	10·6	10·9	33·9
11*b* ...	2·07	1·84	1·96	1·79	0·61	0·46	3·87	4·31	10·5	10·6	31·7
12*b* ...	2·03	1·80	1·97	1·84	0·56	0·52	2·97	3·57	10·6	10·6	32·8
13*b* ...	1·99	1·74	1·95	1·86	0·66	0·62	2·88	2·96	10·5	10·5	32·9
14*b* ...	2·05	1·75	1·97	1·87	0·72	0·53	2·87	3·41	10·7	11·0	32·6
7*b* ...	2·09	1·85	1·99	1·89	0·71	0·56	2·79	2·94	10·6	10·7	32·9
Mean	2·04	1·80	1·98	1·86	0·65	0·54	3·10	3·43	10·6	10·7	32·8
					Straw.						
2.....	0·50	0·43	6·44	6·55	0·45	0·29	3·96	4·25	1·27	1·45	19·9
3.....	0·54	0·47	6·08	6·68	0·73	0·65	5·03	5·12	1·49	1·56	15·9
5*b* ...	0·59	0·44	6·45	6·91	0·74	0·66	4·00	4·20	1·26	1·44	18·8
10*a* ...	0·58	0·55	5·27	5·46	0·64	0·42	5·93	7·41	1·63	2·02	18·2
10*b* ...	0·56	0·56	5·11	5·08	0·84	0·43	5·92	8·02	1·65	2·24	19·4
11*b* ...	0·57	0·58	5·41	5·24	0·58	0·46	5·94	8·56	1·63	2·26	14·8
12*b* ...	0·49	0·42	5·25	5·32	0·52	0·39	5·29	7·27	1·46	1·93	20·1
13*b* ...	0·49	0·48	5·35	5·32	0·50	0·32	5·22	5·91	1·38	1·66	24·1
14*b* ...	0·53	0·46	5·31	5·15	0·48	0·41	5·27	6·90	1·55	2·18	22·0
7*b* ..	0·56	0·43	5·43	5·11	0·56	0·34	5·15	6·00	1·46	1·83	23·7
Mean	0·53	0·48	5·56	5·56	0·60	0·44	5·17	6·36	1·48	1·86	19·7

is very nearly identical, but slightly higher on the two plots receiving potash (13*b* and 7*b*). Further, in the second period, the percentages in the grain-ashes of the same four plots are: 33·3, 33·5, 33·1, and 33·4, again almost identical, but with a tendency to higher results on the two plots having an annual supply. The corresponding straw-ashes, on the other hand, show very wide differences, which have a very marked connection with the known differences as to supply. Thus, the percentages of potash in the straw-ashes of the four plots are, over the first period, 20·1, 24·1, 22·0, and 23·7; and over the second period, with the increasing exhaustion on the first and third plots, 12*b* and 14*b*, they are, 17·2, 25·0, 18·5, and 24·6.

The differences in the percentages of potash in the other grain-ashes are also consistent and significant. The lowest percentages in the grain-ashes are in those of 11*b*, 2, and 5*b*. In the case of 11*b*, with

TABLE XV.

stance of the Grain and Straw of each Plot, over each of the Two Periods; also *stituent in the Pure Ash.*

Potash.	Soda.		Phosphoric acid.		Sulphuric acid.		Chlorine.		Silica.		Plots.
10 years, 1852–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
					Grain.						
32·2	0·22	0·16	52·8	52·2	0·55	0·89	0·01	0·02	0·77	0·56	2
33·2	0·23	0·13	49·8	50·3	1·40	1·44	0·03	0·07	0·71	0·60	3
32·8	0·26	0·10	51·7	50·9	0·82	1·69	0·01	0·02	1·00	0·59	5*b*
34·1	0·18	0·22	46·3	45·8	2·84	3·03	0·59	0·42	1·17	0·66	10*a*
34·1	0·23	0·17	48·6	47·0	1·69	2·26	0·16	0·27	0·78	0·60	10*b*
32·1	0·11	0·26	50·8	49·7	1·56	1·91	0 01	0·18	0·83	0·56	11*b*
33·3	0·19	0·20	51·0	50·0	1·37	1·18	0·01	0·01	0·60	0·57	12*b*
33·5	0·14	0·14	51·5	50·2	0·71	1·43	0·01	0·01	0·71	0·60	13*b*
33·1	0·18	0·10	51·6	50·3	0·73	1·00	0·01	0·01	0·67	0·64	14*b*
33·4	0·20	0·12	51·0	50·1	1·16	1·46	0·01	0·01	0·69	0·64	7*b*
33·2	0·19	0·16	50·5	49·6	1·28	1·63	0·09	0·10	0·79	0·60	Mean.
					Straw.						
19·6	0·11	0·15	3·34	3·43	3·40	2·93	3·30	3·46	65·1	65·2	2
14·3	0·32	0·21	3·09	3·11	4·11	3·57	2·01	2·25	67·8	69·2	3
17·9	0·14	0·21	3·93	4·12	4·32	4·70	2·43	2·46	65·0	64·9	5*b*
14·2	0·35	0·34	3·05	2·79	5·05	4·86	2·87	2·49	62·5	65·5	10*a*
14·8	0·58	1·09	2·97	2·55	4·58	4·40	3·18	3·30	61·6	63·9	10*b*
14·1	1·06	1·96	3·39	3·63	4·35	4·63	2·45	3·75	66·4	61·5	11*b*
17·2	0·53	1·11	3·24	3·14	4·46	4·07	3·58	3·73	61·7	62·0	12*b*
25·0	0·21	0·06	2·98	2·97	4·55	3·89	4·75	5·69	57·4	55·8	13*b*
18·5	0·32	0·73	2·85	3·24	4·60	4·16	4·29	4·05	59·7	60·7	14*b*
24·6	0·23	0·16	2·90	2·98	4·48	4·28	4 56	5·64	58·0	56·4	7*b*
18·1	0·44	0·65	3·17	3·20	4·39	4·15	3·34	3·68	62·5	62·4	Mean.

ammonium-salts and superphosphate, there is forced luxuriance to the utmost limits attainable with the conditions of great exhaustion of potash, which latter is clearly indicated by the very low percentage in the straw-ashes. In the case of Plot 2, with farmyard manure, the low percentages in the grain-ashes are not due to deficient supply, as corroborated by the comparatively high amounts in the straw-ashes; but rather to a full supply of every constituent throughout the periods of growth and maturation, and a different character of ripening accordingly, as indicated by very high phosphoric acid, and very low sulphuric acid. That the percentage is also low in the grain-ashes of Plot 5*b*, with full mineral supply, including potash, but no nitrogen supplied, is doubtless dependent on the total want of luxuriance during the earlier stages, and to eventual sluggish ripening. Lastly, the highest percentages of all are in the grain-ashes of Plots 10*a* and 10*b*, with ammonium-salts alone, giving forced luxuri-

ance as far as the mineral supply will permit, but where there is known great exhaustion of both potash and phosphoric acid, and so far as can be judged, greater of phosphoric acid than of potash; especially in the second period, as indicated by the low percentages in the straw-ashes. These conditions of mineral exhaustion must obviously materially affect the characters of the maturation.

It is at least noteworthy that, with the generally higher percentages of potash in the grain-ashes of the second period with its more favourable seasons, there is also in the case of every plot a higher percentage of lime, and a slight tendency to higher percentage of magnesia over that period. A study of the details further shows, comparing plot with plot, that the percentages of lime are generally the higher where the exhaustion of potash is known to be the greatest, as, for instance, in the grain-ashes of Plots 10*a*, 10*b*, and 11*b*; and again in those of Plots 12*b* and 14*b*, compared with those of 13*b* and 7*b*.

Turning to the phosphoric acid columns, it is seen that there is as distinct a tendency to lower percentages in the grain-ashes of the later and better seasons, as there was to higher percentages of potash over those seasons. This is very marked in the case of the four comparable Plots 12*b*, 13*b*, 14*b*, and 7*b*. The influence of relative exhaustion of phosphoric acid, that is exhaustion having regard to the amount of crop grown, is also very clear. Thus, both the actual and relative exhaustion of phosphoric acid is undoubtedly the greatest on Plots 10*a* and 10*b*, and it is in the grain-ashes of these plots that we have the lowest percentages of phosphoric acid in the first period, and lower still, and again the lowest over the second period.

With the generally lower percentages of phosphoric acid in the grain-ashes in the second ten years, there is in every case (excepting 12*b*) a higher percentage of sulphuric acid; and comparing plot with plot the percentage of sulphuric acid is, over both periods, the highest where the exhaustion, and the percentage, of phosphoric acid are the lowest (10*a* and 10*b*). Again, with the generally lower percentages of phosphoric acid in the grain-ashes over the second period, there is, under every condition as to manuring, a lower percentage of both ferric oxide and silica; and small as are the actual percentages of these constituents in the grain-ashes, the result is too uniform to be without some significance.*

* With regard to both ferric oxide and silica it should be stated, however, that their relative amounts in ashes are very generally found to rise and fall with the amounts of "sand," and as the amounts of this are liable to be higher in the less favourably matured and harvested crops, we should expect less ferric oxide and silica due to adventitious matters in the more favourable seasons. It may be added that the mean percentages of sand in the grain-ashes were, in those of Series 1, 1·66, of Series 2, 0·09, and of Series 3, 0·91; and in the straw-ashes they were, in those of

It may perhaps be considered established that iron plays an important part during the vegetative or green stages of the life of the plant; but there is not evidence of equal weight leading to the conclusion that iron is essential to grain formation; though its accumulation in the seed may be of importance when the young plant grown from it first produces green leaves.

We now turn from a consideration of the percentage composition of the ashes, to that of the relation of the mineral constituents to the organic substance produced. This is shown in Table XVI (pp. 64–65).

It is seen that, with a lower proportion of total ash-constituents in the second and better maturing period, there is (with slight exceptions in the case of the lime and the sulphuric acid), a lower proportion of each individual ash-constituent in the dry substance of the grain under each of the very different conditions as to manuring. This lower proportion of ash-constituents to organic substance produced, is moreover coincident with a lower proportion of nitrogen in the dry substance, under each of the ten conditions as to manuring. It is also coincident with a higher weight per bushel of the grain in every case. The lower proportion of the several ash-constituents is therefore associated with better ripening, a lower proportion of nitrogenous, and a higher proportion of non-nitrogenous, constituents (carbohydrates), produced.

To go a little more into detail:—

It will be remembered that the grain-ashes showed (with one exception) a higher percentage of potash under every condition as to manuring over the second and more favourable period than over the first; but when the potash is calculated, not to 100 of ash, but to 1000 of dry substance, we find with the lower proportion of total mineral matter, a lower proportion of potash in the dry substance of the grain of the later and better maturing period, under every condition of manuring without exception. And whereas there was the apparent anomaly of relatively high percentage of potash in the grain-ash where it was much exhausted (10*a* and 10*b*), we have the lowest proportion to the dry substance produced on the three most potash-exhausted plots (10*a*, 10*b*, and 11*b*), namely, 6·39, 6·39, and 6·22, in the first period, and 5·87, 5·98, and 5·76, over the second period, with its greater exhaustion. The straws of these plots also show the lowest proportion of potash to dry substance.

Again, on the four comparable plots, 12*b*, 13*b*, 14*b*, and 7*b*, the quantities of potash *per* 1000 *dry substance of grain*, are, over the first

Series 1, 2·23, of Series 2, 2·19, and of Series 3, 2·28. Comparing the results for the two periods of Series 3, the mean percentage of sand in the grain-ashes of the first period was 1·09, and of the second period, 0·73; and in the straw-ashes it was, in those of the first period 2·74, and of the second period 1·81.

TABLE XVI.

Quantity of Mineral Matter (pure Ash), and of each Ash-

Plots.	Ash (pure).		Ferric oxide.		Lime.		Magnesia.		Potash.	
	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.	10 years, 1852-'61.	10 years, 1862-'71.
					Grain.					
2	20·6	19·2	0·11	0·09	0·51	0·50	2·25	2·10	6·52	6·18
3	20·8	20·0	0·15	0·11	0·65	0·65	2·17	2·11	6·98	6·65
5*b*	21·0	20·3	0·13	0·11	0·56	0·57	2·21	2·16	6·79	6·66
10*a*	18·8	17·2	0·14	0·11	0·73	0·75	1·96	1·88	6·39	5·87
10*b*	18·8	17·5	0·13	0·10	0·64	0·73	1·99	1·90	6·39	5·98
11*b*	19·6	17·9	0·12	0·08	0·76	0·77	2·06	1·90	6·22	5·76
12*b*	19·7	18·4	0·11	0·09	0·58	0·66	2·08	1·95	6·46	6·14
13*b*	19·5	18·6	0·13	0·11	0·56	0·55	2·05	1·96	6·43	6·22
14*b*	19·7	18·7	0·14	0·10	0·56	0·64	2·11	2·04	6·41	6·16
7*b*	19·9	18·9	0·14	0·11	0·55	0·56	2·11	2·03	6·53	6·33
Mean	19·8	18·6	0·13	0·10	0·60	0·63	2·10	2·00	6·48	6·16
					Straw.					
2	64·4	65·5	0·29	0·19	2·55	2·78	0·81	0·95	12·80	12·83
3	60·8	66·8	0·44	0·43	3·06	3·42	0·91	1·04	9·65	9·91
5*b*	64·5	69·1	0·48	0·45	2·58	2·90	0·81	0·99	12·09	12·34
10*a*	52·7	54·6	0·34	0·23	3·13	4·04	0·86	1·10	9·57	7·76
10*b*	51·1	50·8	0·43	0·22	3·02	4·08	0·84	1·14	9·90	7·53
11*b*	54·1	52·4	0·31	0·24	3·22	4·48	0·88	1·18	8·00	7·37
12*b*	52·5	53·2	0·27	0·21	2·78	3·86	0·77	1·03	10·54	9·14
13*b*	53·5	53·2	0·26	0·17	2·80	3·15	0·74	0·88	12·90	13·29
14*b*	53·1	51·5	0·26	0·21	2·80	3·56	0·82	1·13	11·65	9·55
7*b*	54·3	51·1	0·30	0·17	2·80	3·06	0·79	0·94	12·84	12·58
Mean	55·6	55·6	0·32	0·22	2·86	3·50	0·81	1·03	11·19	10·46

period, 6·46, 6·43, 6·41, and 6·53, or almost identical amounts; and over the second period, 6·14, 6·22, 6·16, and 6·33, that is, lower amounts, and quantities which are nearly, but not quite, as uniform as those over the first period. The differences, slight as they are, are, however, quite consistent with the known differences as to available supply. Thus, the residue from previous applications of potash to plots 12*b* and 14*b* was becoming much reduced, and the accumulations from annual supply to plots 13*b* and 7*b* were becoming greater over the second period; and accordingly there is a slightly lower proportion of potash in the dry substance of the grain of the two potash exhausted plots; and the proportions in the dry substance of the straw of the four plots show very wide differences, due to supply on the one hand, and to exhaustion on the other. Thus, on the two potash exhausted plots, 12*b* and 14*b*, the proportions of potash in the dry substance of the straw are 9·14 and 9·55, and on the two plots with annual supply they are 13·29 and 12·58.

TABLE XVI.

Constituent *per* 1000 *Dry Substance of Grain and of Straw.*

Soda.		Phosphoric acid.		Sulphuric acid.		Chlorine.		Silica.		Plots.
10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
				Grain.						
0·05	0·03	10·87	10·01	0·11	0·17	trace	trace	0·16	0·11	2
0·05	0·03	10·37	10·07	0·29	0·29	trace	0·01	0·15	0·12	3
0·06	0·02	10·86	10·35	0·17	0·35	trace	0·01	0·21	0·12	5*b*
0·03	0·04	8·70	7·89	0·53	0·52	0·11	0·07	0·22	0·11	10*a*
0·04	0·03	9·16	8·24	0·32	0·39	0·03	0·05	0·15	0·11	10*b*
0·02	0·05	9·95	8·92	0·31	0·34	trace	0·03	0·16	0·10	11*b*
0·04	0·04	10·05	9·21	0·27	0·22	trace	trace	0·12	0·10	12*b*
0·03	0·03	10·05	9·31	0·14	0·27	trace	trace	0·14	0·11	13*b*
0·04	0·02	10·15	9·38	0·15	0·19	trace	trace	0·13	0·12	14*b*
0·04	0·02	10·12	9·49	0·23	0·28	trace	trace	0·14	0·12	7*b*
0·04	0·03	10·05	9·25	0·24	0·29	0·01	0·02	0·15	0·11	Mean.
				Straw.						
0·07	0·10	2·15	2·25	2·19	1·92	2·13	2·27	41·91	42·71	2
0·19	0·14	1·88	2·08	2·49	2·39	1·22	1·50	41·19	46·25	3
0·09	0·14	2·53	2·84	2·78	3·25	1·57	1·70	41·88	44·83	5*b*
0·45	0·46	1·61	1·52	2·66	2·66	1·51	1·36	32·94	35·75	10*a*
0·30	0·56	1·52	1·29	2·34	2·23	1·62	1·67	31·47	32·47	10*b*
0·57	1·03	1·84	1·90	2·35	2·42	1·33	1·97	35·94	32·20	11*b*
0·28	0·59	1·70	1·66	2·34	2·17	1·88	1·99	32·39	32·96	12*b*
0·11	0·03	1·59	1·58	2·43	2·06	2·55	3·03	30·70	29·66	13*b*
0·17	0·37	1·51	1·67	2·45	2·14	2·28	2·09	31·69	31·28	14*b*
0·12	0·08	1·57	1·52	2·43	2·19	2·48	2·88	31·50	28·29	7*b*
0·23	0·34	1·75	1·77	2·42	2·25	1·95	2·17	34·48	34·28	Mean.

The percentages of phosphoric acid in the grain-ashes varied more according to supply or exhaustion than did those of the potash, but with one exception (the unmanured plot 3), the percentage was lower over the second period than the first. In every case, without exception, Table XVI shows a lower proportion of phosphoric acid in the dry substance of the grain over the second period; and over both periods a much wider range of variation in the proportion comparing plot with plot, that is, according to supply or exhaustion, than in the case of the potash. Thus, in the first period the proportion of phosphoric acid in 1000 dry substance of the grain ranged from 8·70 with ammonium-salts alone, to 10·87 with farmyard manure; and in the second period from 7·89 with ammonium-salts alone to 10·35 with mineral manure alone. On the other hand, the four plots, 12*b*, 13*b*, 14*b*, and 7*b*, show almost uniform proportions, namely, 10·05, 10·05, 10·15, 10·12, over the first period, and 9·21, 9·31, 9·38, and 9·49, over the second period. The very low proportions of phosphoric acid in

the dry substance of the grain under the conditions of very abnormal exhaustion of it on Plots 10*a* and 10*b*, with ammonium-salts alone, are accompanied, over the first period with very low weight per bushel of the grain, indicating low condition of maturation, and over the second period with lower weights per bushel than on the four plots above referred to. There is also very low proportion of phosphoric acid in the dry substance of the grain of Plot 11*b* with an annual application of superphosphate, and therefore relative excess of phosphoric acid supplied, but with nevertheless very defective grain formation owing to great exhaustion of potash; and here again there is very low weight per bushel. As indicated in the percentage composition of the ash, there is also in proportion to the dry substance, the highest amount of sulphuric acid with the lowest amounts of phosphoric acid in the grain of Plots 10*a* and 10*b*, but by no means in compensating equivalent proportion.

The results of this third series of ash-analyses, specially arranged to trace the effects of supply or exhaustion of ash-constituents on the composition of the ash, and of the crop, agree with those of Series 1 and 2, in showing, in the case of the grain, much greater uniformity in the composition of the ash, and in the proportion of ash-constituents to dry substance, than in that of the straw. It is seen that, under otherwise equal conditions, the amounts of the mineral constituents taken up by the plant over a given area, depend very directly on the amounts in available condition within the soil. Further, with very different amounts so taken up over a given area, the amounts stored up in the grain will, other conditions being equal, be very nearly uniform; whilst the amounts remaining in the straw will have a very obvious connection with the supply or exhaustion.

The results also agree with those of the former series, in showing very distinctly the influence of season on the composition of the grain-ashes, and on the proportion of the ash-constituents to the dry substance of the grain; and that these differences in the mineral composition of the grain, dependent on season, are associated with very different conditions as to maturation, and accordingly with different characters of the organic substance produced.

As, however, this third series of ashes represents the average produce of two periods, respectively of ten years each, which, though of obviously varying average characters, do not show anything like the extremes of individual good and bad seasons, the results do not illustrate in so marked a manner the varying effects of season as do those of Series 1 and Series 2. On the other hand, the analytical results last considered do represent very marked variations in the conditions of supply, or exhaustion, of mineral constituents. Hence, contrary to those before discussed, they show a wider range in the mineral

composition according to manure than according to season. Nevertheless, it is evident that, when the supply of any mineral constituent is not defective below a certain limit in relation to the other conditions of growth, the mineral composition of the grain is very uniform. It is, indeed, very uniform, notwithstanding there may be a very great excess of supply, and a relatively very great excess taken up by the plant, in which latter case a large excess remains in the straw. In fact, the composition of the grain only varies in any marked degree according to manure, when there is very abnormal deficiency of one or more constituents, having regard to the amount of growth which is induced by the liberal supply of others.

At the commencement of our paper, it was stated that it was not proposed to treat the subject exhaustively. Accordingly, attention has mainly been confined to an attempt to point out some of the most important conclusions to which a consideration of the enormous amount of experimental result recorded, seemed to lead. The discussion has nevertheless necessarily been one of much detail. It has at the same time served to raise many points of interest, and to suggest lines of study which neither the time nor the space at our disposal will allow us to follow up. There are, indeed, various aspects of the subject, chemical, physiological, and agricultural, which it might be expected we should consider. Some of these will be more appropriately discussed when the results of the analyses of the ashes of other crops than wheat have been given. Thus, we have a series of ash-analyses relating to the produce of barley grown under different conditions as to season and manuring; a series relating to some leguminous crops, including the bean-plant at different stages of growth; a series relating to root-crops, and to potatoes; a series relating to crops grown in rotation, but with different manures; and lastly, a large series relating to the mixed herbage of grass land, that is to the mixed produce of numerous species of plants growing in association, which are not allowed fully to ripen, but are cut at various stages of development short of complete maturation. In the meantime we submit the results relating to the mineral composition of wheat-grain and wheat-straw, with such comments as their study seemed to suggest, as a substantial contribution to a limited branch of the subject of the ash-constituents of our crops.

In conclusion, extensive and comprehensive as has been the inquiry within its own limits, it must be borne in mind that the results relate to the produce obtained on one description of soil, and in one locality only.* Still, the number of very widely different seasons

* It is true that once within the period to which the results relate, there was a change of seed from one description to another not very widely different; but there

over which the experiments have extended, and the very widely different conditions as to manuring of the different plots, have probably provided a much greater range of conditions of growth than would have been secured had the experiments been made in fewer seasons, on various soils, and in various localities, but with more normal conditions as to manuring. Indeed, the conditions of relative excess, or exhaustion, of the available supply of individual constituents represented in the experiments the results of which have been recorded, are probably much more distinctive and characteristic than could be obtained under more normal conditions. On this view it is obvious that, whilst the results are of a very marked character, and are therefore very instructive if properly interpreted, it must not be without careful reservation that their application to the circumstances of actual agricultural practice should be inferred.

Summary and Conclusions.

The investigation comprises the analyses of 92 wheat-grain and 92 wheat-straw ashes, and, including 69 duplicates, the number of complete ash-analyses involved is 253. Every ash is of produce of known history of growth as to soil, season, and manuring; all the specimens having been grown in the experimental field at Rothamsted which has now yielded wheat for forty years in succession, 1844 to 1883 inclusive. The results are arranged in three Series.

First Series of Analyses.

1. This series includes results obtained under three very characteristically different conditions as to manuring, in each case for sixteen consecutive seasons. The manuring conditions were:—Plot 2, farmyard manure every year; that is, with an excessive supply both of nitrogen, and of mineral, or ash-constituents. Plot 3, without manure every year; that is, with exhaustion of both nitrogen and ash-constituents. Plot 10*a*, with ammonium-salts alone every year; that is, with an excess of supplied nitrogen, but with great relative deficiency of ash-constituents. The results thus illustrate the influence of fluctuations of season from year to year, under known but very different conditions as to manuring.

2. There was a much greater range of variation in the percentages of potash and phosphoric acid in the ashes, both of grain and straw, due to variations of season, than to variations of manure. The range

is no evidence leading to the conclusion that this irregularity has at all vitiated the comparative character of the results, or the legitimacy of the conclusions that have been drawn from them.

of variation due to season, was much the greater in the straw-ashes; which is explained by the fact that favourable or unfavourable seed-forming and ripening may supervene on conditions of high or of low luxuriance, that is, of great or of limited activity of accumulation of constituents by the plant; hence the withdrawal of constituents for seed-formation will leave very various amounts of migratory matters in the straw.

3. Taking high weight per bushel of the grain as a fairly good indication of high quality, and *vice versâ*, there was, with each condition of manuring, a general and marked, but not uniform tendency to low proportions of nitrogen, of total mineral constituents (ash), and of individual ash-constituents, in the dry substance of the grain of the seasons of higher quality. That is, the higher quality of the grain is associated with the greater accumulation of the non-nitrogenous matters (carbohydrates) in proportion to the nitrogen, and to the mineral constituents which have been stored up.

4. *Per* 1000 *dry substance of the grain* there is, with each condition as to manuring, much greater uniformity in the amount, and a rather lower average amount of potash in the eight better than in the eight worse seasons. Yet, it is in a very unfavourable season that there was actually the lowest, and in the worst season of the sixteen that there was actually the highest, proportion of potash in the dry substance of the grain; that is, the very different results are obtained under defective, but very different, conditions of development and maturation.

5. *Per* 1000 *dry substance of the grain* there is, under each of the three conditions as to manuring, a lower average amount of phosphoric acid over the eight better seasons, and it is lower in individual seasons of high quality. Still there is a wider range than among the eight inferior seasons, and wider than in the case of the potash. In the case of the farmyard manure plot, the lower proportion of phosphoric acid in the better seasons cannot be due to exhaustion, but to enhanced production of organic substance. The average proportion of phosphoric acid to organic substance is, however, lower without manure than with farmyard manure, and lower still with ammonium-salts alone, in which case there is very abnormal mineral exhaustion.

6. The details illustrate in a striking manner the greater influence of season than of manuring on the proportion of the ash-constituents to the organic substance of the grain. With normal maturation it is, under otherwise comparable conditions, nearly uniform with different conditions as to manuring; and deviations from normal mineral composition are associated with deviations from normal development of the organic substance.

7. The percentage of silica in the dry substance of the straw is

lower in the seasons of more favourable maturation. In fact, stiffness of straw depends on favourable development of the woody substance, by the increase of which the proportion of the accumulated silica to the organic substance is reduced.

8. Excluding the ferric oxide and the silica, and calculating the whole of the phosphoric acid as tribasic, the grain-ashes show more than one and a half time as much acid as base; and even calculating the whole of the phosphoric acid, whether combined with alkalis or earths, as bibasic, there is still an excess of acid. The straw-ashes, calculated in the same way, show a considerable excess of base, even reckoning the whole of the phosphoric acid as tribasic; but they contain more than 60 per cent. of silica. The question arises whether carbonic acid (if any), and some sulphuric acid and chlorine, have not been expelled in the incineration; in the case of the grain-ashes in the presence of acid-phosphates, and in that of the straw-ashes in the presence of an excess of silica.

9. Investigations at Rothamsted and elsewhere have established that there is a general increase in the percentage of nitrogen proceeding from the finer to the coarser flours obtained from the same wheat-grain, and that there is marked increase in the more branny portions, the greatest concentration being immediately below the pericarp. The percentage of potash, lime, magnesia, and phosphoric acid, also increases from the finer to the coarser flours, and it is the highest in the branny products. The percentage of potash is about ten times, of lime four or five times, of magnesia fifteen to twenty times, and of phosphoric acid more than ten times, as high in the dry substance of the bran as in that of the finer flours. It is also established that, in comparable cases, the better matured grains contain the lower percentages of nitrogen and total mineral matter, and a higher percentage of starch; and the ash-analyses now under consideration consistently show a lower proportion of the chief individual mineral constituents in the grains of better quality.

10. The average annual amounts of total mineral constituents in the crops *per acre* (grain and straw) over the sixteen years were—with farmyard manure 237·4 lbs., without manure 106·1 lbs., and with ammonium-salts alone 142 lbs.; that is, with ammonium-salts one and a third time, and with farmyard manure more than twice, as much as without manure. With ammonium-salts, the greatest proportional increase was in lime, potash, magnesia, soda, sulphuric acid, and chlorine, and the least in phosphoric acid. With farmyard manure, by far the greatest increase was in potash, of which there is more than two and a half times as much as without manure; and there is about twice as much magnesia, and more than twice as much lime, phosphoric acid, sulphuric acid, soda, and silica, and nearly four times as much chlorine.

11. Comparing the amounts of the individual ash-constituents *in the crops per acre* over the first eight years with those over the second eight, they are, without manure, in the grain nearly identical; but in the straw there is more or less deficiency of every constituent, excepting lime, over the second period. Deficiency in the straw and total produce generally, but not uniformly, indicates deficient source. With farmyard manure, there was more of every ash-constituent (excepting sulphuric acid), in the grain, straw, and total produce, over the second period; the most marked increase being, in the grain in potash and phosphoric acid, and in the straw in potash and silica. With ammonium-salts alone there was, over the second period, in the grain slight deficiency of potash and magnesia, and greater in phosphoric acid, but there was slight increase in lime and sulphuric acid. In the straw there was more marked deficiency in every constituent, excepting sulphuric acid, and the deficiency is the most marked in potash, phosphoric acid, chlorine, and silica, though chlorine is largely supplied in the ammonium-salts.

12. Upon the whole, the comparison of the yield of ash-constituents *per acre* over the first and second eight years shows—without manure a small relative exhaustion of both potash and phosphoric acid, and with ammonium-salts a greater relative exhaustion of both.

13. *Per* 1000 *dry substance of grain* there were, taking the average of the sixteen years, almost identical amounts of each of the ash-constituents without manure, and with farmyard manure; but with ammonium-salts alone there was marked deficiency, especially of phosphoric acid, and in a less degree of potash. *Per* 1000 *dry substance of straw*, there was, without manure considerably less potash than with farmyard manure, but otherwise not much difference. With ammonium-salts alone, there was still greater deficiency of potash, but more lime, less phosphoric acid, but more sulphuric acid, and considerably less silica, than either without manure or with farmyard manure.

14. Comparing the amounts of ash-constituents *per* 1000 *dry substance of the grain, over the first and second eight years*, with farmyard manure they are almost identical over the two periods, and without manure very nearly so, but there is slightly less potash, and more magnesia and phosphoric acid, over the second period—conditions indicating less perfect maturation, that is, less flour in proportion to bran. With ammonium-salts alone, the dry substance of the grain shows a marked deficiency of potash and magnesia, and especially of phosphoric acid, compared with that of the other plots; it nevertheless shows very little difference comparing the second eight years with the first, though there is a slight decrease of phosphoric acid, and increase of sulphuric acid and silica, over the second period.

15. *Per* 1000 *dry substance of the straw*, the amount of the various ash-constituents varies more over the two periods than in the case of the grain, but still comparatively little. Without manure there is, over the second period, a deficiency of potash and magnesia, partially compensated by lime, also a deficiency of phosphoric acid. With ammonium-salts, the most marked deficiency over the second period is of potash; there is also less chlorine, but more sulphuric acid.

16. In conclusion, in regard to this first series of ash-analyses, although the results show a much wider range of variation in the mineral composition of the grain due to season than to manuring, there are still distinct differences due to the very different conditions as to manuring; but with each of the three conditions there is comparatively little difference over the first and the second eight years. With ammonium-salts alone, where there is very abnormal mineral exhaustion, the dry substance of the grain shows relative deficiency of both potash and phosphoric acid, but especially the latter. Upon the whole, the results point to great uniformity in the mineral composition of the grain under the different conditions of manuring, provided only that it is perfectly and normally ripened. High or low percentage of nitrogen is also more dependent on the conditions of maturation than on full or limited supply of it by the soil.

Second Series of Analyses.

1. This series relates to the produce obtained under nine different conditions as to manuring, each in two unfavourable, and in two favourable seasons for the crop. They thus illustrate the influence of characteristic seasons under a great variety of manuring conditions.

2. The manuring conditions were:—Farmyard manure; without manure; superphosphate, and sodium, potassium, and magnesium sulphates; ammonium-salts alone; ammonium-salts and superphosphate; ammonium-salts, superphosphate, and sodium sulphate; ammonium-salts, superphosphate, and potassium sulphate; ammonium-salts, superphosphate, and magnesium sulphate: ammonium-salts, superphosphate, and sodium, potassium, and magnesium sulphates.

3. The four seasons were:—1852 and 1856, which were unfavourable, and 1858 and 1863, which were favourable for the crop. 1852 (the ninth from the commencement of the experiments) was bad both as to quantity and quality of produce. 1856 gave fairly average quantity, both of grain and straw, but the crop was unevenly ripened, and the quality of the grain was low. 1858 yielded only a moderate amount of total produce, but more than average proportion and amount of grain, which was of over average quality. 1863 (the

twentieth year of the experiments) was the best both as to quantity and quality of produce throughout the forty years, 1844–1883, inclusive.

4. Taking the mean results of the nine plots in each of the four seasons, there was from the first to the fourth season an increase in the weight per bushel of the grain, and in the proportion of grain to straw, and a decrease in the percentages of nitrogen and total mineral matter in the dry substance of the grain. Coincidently with these characters, there was, from the first to the fourth season, great increase in the percentage of potash, and considerable decrease in that of magnesia, and there was great decrease in the percentage of phosphoric acid, and an increase in that of sulphuric acid, *in the grain-ash.*

5. *Calculated per* 1000 *dry substance of the grain*, there was more potash, and less magnesia, and especially much less phosphoric acid, and some more sulphuric acid, in the produce of the two later and better seasons. These are indications of higher proportion of flour to bran, that is, of more starch. The variation in the mineral composition is thus associated with variation in the organic composition of the grain. *Per* 1000 *dry substance of the straw*, there was also more potash, less phosphoric acid, and more sulphuric acid, in the better seasons.

6. *Calculated per acre*, there was about twice as much grain, nearly one and a half time as much straw, and more than one and a half time as much total produce, in the best as in the worst of the four seasons. Of total nitrogen *in the crops per acre*, there was an average of only 38 lbs. in 1852, and of 50·1 lbs. in 1863; whilst of the less total quantity in 1852 a considerably larger actual amount remained in the straw. In 1852, 61·6 per cent., in 1856, 72·9 per cent., in 1858, 73·8 per cent., and in 1863, 77·4 per cent., of the total nitrogen of the crops was stored up in the grain. In 1863, with the largest actual amount of nitrogen in the grain *per acre*, there was the lowest *percentage of it in the grain;* that is, under the influence of the very favourable growing and maturing conditions, there was a greater accumulation of non-nitrogenous constituents in proportion to the amount of nitrogen stored up.

7. *Calculated per acre*, there was, in 1863, one and a third time as much total mineral matter in the crop as in either of the other years. Comparing the best and the worst seasons (1863 and 1852), there was one and a half time as much lime, magnesia, and phosphoric acid, and about twice as much potash and sulphuric acid, in the total produce *per acre*, in the season of most favourable growth and maturation. Yet, *per* 1000 *dry substance of the grain*, the amounts of lime, magnesia, and phosphoric acid were lower, and the amount of potash was not much higher, in the better seasons.

8. Taking the average results over the four years, for each of the nine different conditions as to manuring separately, there is, with one or two exceptions, comparatively little variation in weight per bushel with the equal season, but very varying manuring conditions; and the differences, such as they are, are consistent. The percentage of nitrogen is also in the main fairly uniform with the different manures; but it is low with mineral manure alone and great nitrogen exhaustion, and high with ammonium-salts alone and relatively excessive nitrogen supply. The percentages of total mineral matter are also fairly uniform; but somewhat high with farmyard manure, without manure, and with mineral manure alone, and low with ammonium-salts alone.

9. *Per* 1000 *dry substance of the grain*, there is also general uniformity in the amount of the chief individual ash-constituents under the very different manuring conditions. The exceptions to uniformity in the amounts of potash are, that it is somewhat high without manure and with purely mineral manure, and somewhat low with ammonium-salts alone, and with ammonium-salts and superphosphate, but without potash. The exceptions to general uniformity in the amounts of phosphoric acid are, that it is high with farmyard manure, without manure, and with purely mineral manure, and low with ammonium-salts alone.

10. *Per* 1000 *dry substance of the straw*, the amounts of the individual ash-constituents are much more variable on the different plots. The variation is especially marked in the case of the potash and phosphoric acid, and it is obviously much dependent on their supply. It is also very marked in the case of the silica.

11. *Calculated per acre*, there is very great variation in the amounts of produce, and of its various constituents, according to manure. Without manure, and with purely mineral manure, the produce was very small; it was much more with ammonium-salts alone, and much more still with ammonium-salts and mineral manure together. With ammonium-salts and the most complete mineral manure, there was more than one and a half time as much total produce as with ammonium-salts alone, and nearly two and a half times as much as with mineral manure alone. There were in the main corresponding differences in the amounts of nitrogen, total mineral matter, and the chief individual ash-constituents, stored up in the crops.

12. Of potash, the ashes show three times as much in the total produce *per acre* with farmyard manure, and more than three times as much in that with ammonium-salts and mineral manure containing potash, as without manure. On the other plots (excepting with mineral manure alone), the quantities of potash in the crops are obviously dependent on the supply. Of the total potash of the crops,

there is generally only from one-fourth to one-third accumulated in the grain.

13. Of phosphoric acid, there was little more than twice as much *per acre* in the highly manured as in the unmanured produce; but three-fourths or more of the total phosphoric acid of the crop may be accumulated in the grain.

14. Of the total lime and sulhuric acid of the crop, a very small proportion, of the magnesia generally more than half, of the chlorine scarcely a trace, and of the silica the smallest proportion of all, is found in the grain-ashes.

15. With very great variation in the amounts of nitrogen and ash-constituents *in the total crop per acre* on the different plots, there is remarkable uniformity in the amounts of each *per* 1000 *dry substance of grain;* but wide variation in the amounts *per* 1000 *dry substance of straw.* The greatest exceptions to uniformity in the amount of potash per 1000 dry substance of the grain are, that it is low with ammonium-salts alone, or with superphosphate only in addition (10*a* and 11*a*), and high without manure, and with purely mineral manure (3 and 5*a*). The most marked deviations from general uniformity in the amount of phosphoric acid in the dry substance of the grain are, that it is low with ammonium-salts alone (10*a*), and high with farmyard manure, without manure, and with purely mineral manure (2, 3, and 5*a*).

16. With every condition of manuring there is, *in the grain ashes*, a higher percentage of potash, and lower of phosphoric acid, and somewhat lower of magnesia also, in the two favourable seasons, indicating higher proportion of flour to bran. There is lower percentage of phosphoric acid in the better seasons even where there is liberal supply of it, but the lowest is on Plot 10*a*, where it is the most exhausted. The *straw-ashes* also show a higher percentage of potash in the two better seasons.

17. With decline in the percentage of phosphoric acid in the ashes, there is increase in sulphuric acid; and in the straw-ashes increase of chlorine in a greater degree. It is a question how far the small amounts of sulphuric acid and chlorine in the grain-ashes are due to the presence of so much acid-phosphate; and how far the much larger amounts in the straw-ashes are due to their excess of base to acid, other than silica, although of this there is so much.

18. *Calculated per* 1000 *dry substance of the grain*, there is, with every condition as to manuring, a higher amount of potash in 1858 and almost without exception in 1863, than in the two unfavourable seasons. On the other hand, the proportion of phosphoric acid is in 1858 almost without exception, and in 1863 without exception, lower than in the unfavourable seasons.

19. The second series of analyses, as did the first, consistently show considerable variation in the mineral composition of wheat-grain, according to season, but little according to manuring (excepting in cases of abnormal exhaustion), provided the seed be properly matured. In fact, variations in the mineral composition are associated with differences in the organic composition.

Third Series of Analyses.

1. This series was more specially arranged to trace the influence of supply or exhaustion. The ashes represent the produce obtained under ten different conditions as to manuring, each over ten years, 1852–1861, and ten years, 1862–1871. Nine of the plots are substantially duplicates of those to which Series 2 relates; and the tenth, 10*b*, is a duplicate of 10*a*, with ammonium-salts alone, excepting that twice prior to the period now under consideration it received mineral manure, including potash and phosphoric acid, when 10*a* did not.

2. The average results *per acre*, of the ten plots, for each of the two periods, show that the first ten years were on the average the more favourable for luxuriance, that is, for total accumulation by the plant, and the second ten the more favourable for seed-formation and maturation. Accordingly, with less mineral matter in the total produce per acre over the second ten years, there was as much or more of almost every individual ash-constituent accumulated in the grain.

3. With each condition of manuring where the nitrogen supply was not deficient, there was more grain, and of better quality, over the second ten years. Comparing plot with plot, there was, over both periods, with equal nitrogen supply, considerable increase by the addition of superphosphate and potash. Comparing the second period with the first, the influence of supply, or exhaustion, especially of potash, is very marked (10*a*, 10*b*, 11*b*, 12*b*, 14*b*, 13*b*, and 7*b*).

4. With equal supply of nitrogen, very variable amounts of it are found in the total produce per acre of the different plots, according to the associated mineral supply.

5. Of individual ash-constituents there was more in the *total produce per acre* with some of the artificial manures than with farmyard manure. Comparing the plots with equal ammonium-salts but different potash supply, the amounts of potash in the total produce are in the order of the supply.

6. Comparing Plots 12*b*, 13*b*, 14*b*, and 7*b*, all with the same nitrogen supply, but the first and third with a decreasing residue of potash from previous applications, and the second and fourth with an annual supply of it, the amounts of potash in the *total produce per acre per*

annum over the first ten years are—45·4, 53·2, 49·8, and 56·0, but the amounts in the grain are 11·4, 11·3, 11·3, and 11·9; over the second period, with the further exhaustion on the first and third plots (12*b* and 14*b*), the amounts of potash in the total produce are 37·8, 55·2, 39·1, and 53·0, but the amounts accumulated in the grain are 11·4, 12·2, 11·6, and 12·3. Thus, the amounts in the total produce are directly influenced by the supply or exhaustion, especially over the second period; but over each period the amounts in the grain are nearly identical on the four plots, showing only slight relative deficiency over the second period on Plots 12*b* and 14*b*, with their reducing residue of potash supply.

7. The amount of phosphoric acid in the *total produce per acre* varies much with equal supply of it, and of nitrogen, and is obviously much dependent on the available supply of potash. The amounts of mineral constituents accumulated in the total plant (as indicated by the amounts in the total crop) are very directly influenced by the supply or exhaustion; but, other things being equal, the final distribution in the grain is influenced much more by the seed-forming characters of the season than by the amounts of the constituents in the total plant, provided there be not a deficiency.

8. *Percentage Composition of the Ashes.*—As in the case of the mean results for the ten plots, so in that of each plot (excepting plot 3, without manure), there is a higher percentage of potash in the grain-ashes of the second period with its better seed-forming and maturing tendencies. The percentage of potash in the grain-ashes only varies from 31·7 to 34·0 over the first, and from 32·1 to 34·1 over the second period; but in the straw-ashes it varies from 14·8 to 24·1 over the first, and from 14·1 to 25·0 over the second period. The variations in the straw-ashes are consistent with the variations in the supply.

9. Comparing Plots 12*b*, 13*b*, 14*b*, and 7*b*, the percentages of potash in the grain-ashes are—over the first period 32·8, 32·9, 32·6, and 32·9, and over the second period 33·3, 33·5, 33·1, and 33·4; but in the straw-ashes they are—over the first period 20·1, 24·1, 22·0, and 23·7, and over the second period, with the increasing exhaustion on the first and third plots (12*b* and 14*b*), 17·2, 25·0, 18·5, 24·6.

10. With higher percentages of potash in the grain-ashes over the second period, there are also higher percentages of lime, and there is a tendency to higher percentages of magnesia; but there is in every case, excepting without manure, a lower percentage of phosphoric acid, and with this, in every case but one, a higher percentage of sulphuric acid, over the second period.

11. *Per* 1000 *dry substance of the grain* there is generally a lower amount of each ash-constituent (excepting lime and sulphuric acid)

over the later and better seed-forming and maturing period; there is also a lower amount of nitrogen, and therefore a higher proportion of non-nitrogenous constituents. Comparing plot with plot, the amounts of potash *per* 1000 *dry substance of the grain* are fairly uniform; but even in the grain, and in the straw in a much more marked degree, it is lowest where it is the most exhausted. Comparing Plots 12*b*, 13*b*, 14*b*, and 7*b*, the amounts *per* 1000 *dry substance of the grain* are—over the first period 6·46, 6·43, 6·41, and 6·53, and over the second period 6·14, 6·22, 6·16, and 6·33; but in the straw they are—over the first period 10·54, 12·90, 11·65, and 12·84, and over the second period, with the increasing exhaustion on the first and third plots, 9·14, 13·29, 9·55, and 12·58.

12. The amounts of phosphoric acid *per* 1000 *dry substance of the grain* varied more according to supply than did that of the potash; but it was, with every condition of manuring, lower over the second and more favourable period. Over the first period, it ranged from 8·70 to 10·87, and over the second from 7·89 to 10·35. On Plots 12*b*, 13*b*, 14*b*, and 7*b* it was—over the first period 10·05, 10·05, 10·15, and 10·12, and over the second period 9·21, 9·31, 9·38, and 9·49, or much lower over the second period, but within each period almost uniform on the four plots. Taking the whole series of plots, it was the lowest on 10*a* and 10*b*, where it was most exhausted, but it was also low on 11*b*, where it was annually supplied, though without potash, and with defective development accordingly.

13. The results of the third series of analyses agree with those of the first and second in showing, upon the whole, marked uniformity in the mineral composition of the ripened grain, even when there is wide variation in that of the straw dependent on supply or exhaustion. They also show distinct influence of season, and that the differences in the mineral composition of the grain due to season are associated with differences in the organic composition. With less variation in the conditions of season, and of influence therefrom, but with a wider range of mineral supply, or exhaustion, than in the other series, there is a wider range in the mineral composition of the grain according to supply or exhaustion; it is, however, comparatively little influenced by excess of supply, but more by deficiency. The three series show that, under otherwise comparable conditions, there is, in the better matured grain, that is in the grain of higher quality, a lower percentage of total mineral matter (ash); *in the ash*, a higher percentage of potash, but lower of phosphoric acid; but *in the dry substance of the grain*, generally a lower percentage of potash, and considerably lower of phosphoric acid, and also a lower percentage of nitrogen.

APPENDIX-TABLES,

I—XV.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table I.—General Characters of the Produce, and *Percentage Com-*
Straw, in sixteen consecutive

Plot 2.—Farmyard Manure, every year.

Harvests	1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw	56·0	68·3	57·3	66·2	49·6	33·2	60·1	58·2
Weight per bushel of grain, lbs.	58·2	63·8	61·9	63·6	58·2	51·1	62·5	62·0
Composition of the Grain, per cent.								
Dry matter	79·68	82·76	83·92	84·50	83·25	80·27	85·88	83·68
Nitrogen in dry matter	1·89	1·58	1·86	1·57	2·02	1·76	1·70	2·19
Ash (pure) in dry matter	2·03	1·93	2·04	1·93	1·98	2·20	1·98	2·08
Composition of the Grain-Ash (pure), per cent.								
Ferric oxide	1·23	0·78	1·15	0·88	0·95	0·83	0·62	0·70
Lime	2·41	2·52	2·80	2·88	2·79	2·60	2·46	2·49
Magnesia	10·81	10·55	11·07	11·11	12·77	10·15	11·27	11·04
Potash	30·15	33·07	31·35	32·36	27·22	35·46	31·97	30·91
Soda	0·57	0·68	0·81	0·50	0·45	0·54	0·48	0·84
Phosphoric anhydride	52·66	50·33	50·48	50·69	54·69	47·05	52·21	53·29
Sulphuric anhydride	0·55	1·51	1·42	0·92	0·14	2·35	0·47	0·03
Chlorine	0·08	0·03	none	trace	trace	0·11	0·02	none
Silica	1·56	0·53	0·92	0·66	0·99	0·93	0·50	0·70
Total	100·02	100·09	100·00	100·00	100·00	100·02	100·00	100·00
Deduct O = Cl	0·02	—	—	—	—	0·02	—	—
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Composition of the Straw, per cent.								
Dry matter	81·46	82·46	82·50	85·42	82·16	80·66	84·89	84·00
Nitrogen in dry matter	0·49	0·45	0·50	0·48	0·46	0·73	0·35	0·43
Ash (pure) in dry matter	6·49	6·64	6·27	6·66	7·04	6·64	4·90	7·40
Composition of the Straw-Ash (pure), per cent.								
Ferric oxide	0·59	0·78	0·61	0·44	0·85	0·44	0·33	0·28
Lime	4·00	5·09	5·21	4·20	3·87	3·22	5·31	3·57
Magnesia	1·27	1·76	2·14	1·87	1·52	1·36	1·96	1·30
Potash	15·73	17·19	19·05	17·72	12·86	20·14	19·66	21·01
Soda	0·28	0·55	0·94	0·54	0·60	0·52	0·46	0·45
Phosphoric anhydride	4·52	2·98	4·26	4·60	3·21	6·21	3·04	3·89
Sulphuric anhydride	2·92	3·27	3·62	3·34	2·58	3·55	4·62	2·36
Chlorine	2·05	2·93	3·80	2·77	1·86	2·68	3·24	5·02
Silica	69·10	66·11	61·23	65·15	73·07	62·48	62·11	63·23
Total	100·46	100·66	100·86	100·63	100·42	100·60	100·73	101·11
Deduct O = Cl	0·46	0·66	0·86	0·63	0·42	0·60	0·73	1·11
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Straw, grown at Rothamsted, year after year on the same Land.

position of the Ash (excluding Sand and Charcoal), of the Grain, and of the Seasons, 1848–1863.

Plot 2.—Farmyard Manure, every year.

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
52·8	77·9	65·5	47·1	54·2	71·0	58·3	67·5	58·6	Grain to 100 straw.
58·6	60·4	62·6	56·5	55·5	60·5	61·0	63·1	60·0	Wt. per bushel of grain, lbs.
				Composition of the Grain, per cent.					
82·58	85·63	83·56	82·70	85·50	84·65	83·27	84·63	83·75	Dry matter.
1·89	1·97	1·91	2·09	2·00	1·95	1·57	1·52	1·83	Nitrogen } in dry matter.
1·98	1·94	2·04	2·11	2·15	2·15	1·99	1·85	2·01	Ash (pure) } in dry matter.
				Composition of the Grain-Ash (pure), per cent.					
0·86	1·05	0·90	0·78	1·02	0·49	0·76	0·43	0·84	Ferric oxide.
2·53	2·88	2·61	2·37	2·78	2·52	2·51	2·34	2·59	Lime.
11·71	11·97	11·17	11·18	10·13	10·29	11·12	11·41	11·11	Magnesia.
29·27	29·84	31·87	31·18	33·78	33·13	32·00	31·54	31·57	Potash.
0·42	0·77	0·28	0·54	0·65	0·65	0·66	0·66	0·59	Soda.
54·18	52·53	51·88	52·64	49·44	51·41	51·61	52·04	51·70	Phosphoric anhydride.
0·23	0·46	0·75	0·51	0·87	1·01	0·51	0·93	0·79	Sulphuric anhydride.
0·07	0·01	0·06	trace	0·07	none	none	trace	0·03	Chlorine.
0·75	0·49	0·49	0·80	1·28	0·50	0·83	0·65	0·79	Silica.
100·02	100·00	100·01	100·00	100·02	100·00	100·00	100·00	100·01	Total.
0·02	—	0·01	—	0·02	—	—	—	0·01	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.
				Composition of the Straw, per cent.					
83·08	84·42	85·24	84·68	85·00	85·83	83·88	84·44	83·81	Dry matter.
0·28	0·39	0·47	0·40	0·56	0·43	0·37	0·25	0·44	Nitrogen } in dry matter.
6·57	5·45	6·42	6·24	7·91	7·17	6·69	6·42	6·52	Ash (pure) } in dry matter.
				Composition of the Straw-Ash (pure), per cent.					
0·49	0·80	0·44	0·61	0·84	0·23	0·39	0·18	0·52	Ferric oxide.
3·98	5·46	4·03	4·56	3·20	3·39	3·23	3·78	4·13	Lime.
1·57	1·61	1·69	1·34	1·06	1·20	1·34	1·41	1·52	Magnesia.
14·62	20·11	21·70	18·62	16·70	25·62	14·53	17·97	18·33	Potash.
0·53	0·44	0·49	0·54	0·51	0·71	0·54	none	0·51	Soda.
3·42	3·46	3·41	3·52	4·04	3·62	3·28	3·16	3·79	Phosphoric anhydride.
2·62	2·67	3·57	2·04	2·54	3·50	2·29	2·54	3·00	Sulphuric anhydride.
2·29	4·01	4·81	2·78	1·95	4·98	1·84	3·61	3·16	Chlorine.
71·00	62·31	60·95	66·62	69·60	57·87	72·98	68·16	65·75	Silica.
100·52	100·87	101·09	100·63	100·44	101·12	100·42	100·81	100·71	Total.
0·52	0·87	1·09	0·63	0·44	1·12	0·42	0·81	0·71	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table II.—General Characters of the Produce, and *Percentage* of the Straw, in sixteen con-

Plot 3.—Unmanured, every year.

Harvests	1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw	55·6	76·1	58·2	66·6	53·9	25·4	63·6	60·0
Weight per bushel of grain, lbs.	57·3	61·4	60·6	61·1	56·6	45·9	60·6	59·2
Composition of the Grain, per cent.								
Dry matter	80·34	82·28	83·80	84·30	82·57	80·12	84·67	84·76
Nitrogen } in dry matter	2·17	1·73	1·83	1·67	2·08	2·09	1·92	2·14
Ash (pure) } in dry matter	2·00	1·88	2·02	1·94	2·03	2·36	1·95	2·02
Composition of the Grain-Ash, per cent.								
Ferric oxide	1·37	1·07	1·32	0·72	1·07	1·26	0·60	0·61
Lime	2·87	3·15	2·98	2·98	2·87	3·09	2·67	2·64
Magnesia	10·35	9·72	9·86	10·16	11·67	10·27	10·44	9·93
Potash	31·19	35·34	32·97	34·74	29·66	35·49	34·18	33·92
Soda	0·66	0·42	0·91	0·45	0·61	0·54	0·73	0·49
Phosphoric anhydride	51·41	47·71	49·68	49·07	51·79	45·55	49·35	50·79
Sulphuric anhydride	0·79	1·83	1·14	1·13	0·99	2·40	1·56	0·65
Chlorine	0·02	0·02	0·04	0·03	0·04	0·19	0·02	0·06
Silica	1·34	0·74	1·11	0·72	1·31	1·25	0·45	0·92
Total	100·00	100·00	100·01	100·00	100·01	100·04	100·00	100·01
Deduct O = Cl	—	—	0·01	—	0·01	0·04	—	0·01
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Composition of the Straw, per cent.								
Dry matter	81·00	82·08	82·64	84·28	82·84	81·59	83·30	82·77
Nitrogen } in dry matter	0·53	0·49	0·53	0·57	0·57	0·85	0·39	0·48
Ash (pure) } in dry matter	6·77	7·02	7·03	6·54	7·04	6·27	5·16	7·30
Composition of the Straw-Ash, per cent.								
Ferric oxide	1·12	1·01	0·47	0·78	1·03	0·94	0·49	0·48
Lime	2·78	2·84	2·71	2·85	2·52	4·42	5·21	2·66
Magnesia	2·21	3·41	3·23	2·79	2·64	1·72	1·82	1·85
Potash	13·36	14·85	15·13	16·84	10·54	14·25	17·85	16·67
Soda	0·33	0·81	0·48	0·33	0·52	0·72	0·51	0·40
Phosphoric anhydride	4·20	2·98	4·71	5·37	3·56	5·96	3·19	3·16
Sulphuric anhydride	2·05	2·83	3·11	3·63	2·37	3·32	4·76	2·52
Chlorine	1·43	1·86	2·05	2·21	1·08	1·10	2·50	2·80
Silica	72·84	69·82	68·57	65·70	75·98	67·82	64·23	70·09
Total	100·32	100·41	100·46	100·50	100·24	100·25	100·56	100·63
Deduct O = Cl	0·32	0·41	0·46	0·50	0·24	0·25	0·56	0·63
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Straw, grown at Rothamsted, year after year on the same Land.

Composition of the Ash (excluding Sand and Charcoal), of the Grain, and secutive seasons, 1848–1863.

Plot 3.—Unmanured, every year.

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
57·3	78·3	68·3	48·3	50·6	58·7	58·2	70·4	59·5	Grain to 100 straw.
54·3	58·3	60·4	52·5	52·6	57·4	57·8	62·7	57·4	Wt. per bushel of grain, lbs.
					Composition of the Grain, per cent.				
82·18	84·91	83·55	82·37	83·10	85·12	82·35	83·97	83·33	Dry matter.
1·91	1·91	1·86	1·96	1·92	2·04	1·76	1·65	1·90	Nitrogen } in dry matter.
2·04	1·92	2·02	2·08	2·16	2·19	2·03	1·95	2·01	Ash (pure) }
					Composition of the Grain-Ash, per cent.				
0·87	1·09	1·03	0·96	1·61	1·05	1·32	0·51	1·03	Ferric oxide.
2·55	3·39	2·76	2·75	2·71	2·68	2·54	2·66	2·83	Lime.
10·76	10·81	10·50	10·98	9·14	9·56	10·24	10·91	10·33	Magnesia.
30·55	32·00	32·74	31·94	33·59	34·42	32·33	32·32	32·96	Potash.
0·65	0·42	0·49	0·41	0·74	0·53	1·18	0·76	0·62	Soda.
52·56	50·00	50·85	50·59	47·44	47·47	49·56	51·58	49·71	Phosphoric anhydride.
1·06	1·28	0·66	1·25	2·21	1·66	1·60	0·67	1·31	Sulphuric anhydride.
trace	0·05	none	0·08	0·24	0·15	0·07	none	0·06	Chlorine.
1·00	0·97	0·97	1·06	2·37	2·51	1·18	0·59	1·16	Silica.
100·00	100·01	100·00	100·02	100·05	100·03	100·02	100·00	100·01	Total.
—	0·01	—	0 02	0·05	0·03	0·02	—	0·01	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.
					Composition of the Straw, per cent.				
84·17	84·36	85·42	84·52	85·57	85·35	83·58	84·07	83·58	Dry matter.
0·41	0·45	0·45	0·51	0·58	0·63	0·44	0·33	0·50	Nitrogen } in dry matter.
5·67	4·82	5·54	5·33	8·33	6·85	6·89	7·12	6·44	Ash (pure) }
					Composition of the Straw-Ash, per cent.				
1·16	1·64	0·67	0·92	1·32	0·32	0·67	0·34	0·84	Ferric oxide.
4·61	2·89	6·10	6·07	4·10	4·28	3·76	4·39	3·89	Lime.
1·70	3·50	2·18	1·59	1·03	1·45	1·30	1·48	2·12	Magnesia.
11·87	15·08	17·29	13·11	11·54	20·68	10·93	13·02	14·56	Potash.
0·59	2·12	0·62	0·64	0·34	0·35	0·35	0·26	0·59	Soda.
4·00	3·51	3·01	3·66	3·48	3·68	3·06	3·16	3·79	Phosphoric anhydride.
3·16	2·73	4·41	3·42	2·39	4·05	2·63	2·87	3·14	Sulphuric anhydride.
1·46	2·16	2·61	1·40	1·14	3·19	1·21	2·04	1·89	Chlorine.
71·78	66·85	63·70	69·50	74·92	62·72	76·37	72·90	69·61	Silica.
100·33	100·48	100·59	100·31	100·26	100·72	100·28	100·46	100·43	Total.
0·33	0·48	0·59	0·31	0·26	0·72	0·28	0·46	0·43	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table III.—General Characters of the Produce, and *Percentage* of the Straw, in sixteen con-

Plot 10a.—Ammonium-Salts alone, every year.

Harvests	1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw	56·3	75·1	55·7	64·0	47·3	31·3	61·5	51·2
Weight per bushel of grain, lbs.	58·1	62·3	60·2	61·9	55·9	48·6	60·5	57·1
Composition of the Grain, per cent.								
Dry matter	81·19	82·71	84·33	84·47	83·75	80·45	84·85	84·20
Nitrogen } in dry matter	2·42	1·95	2·13	2·15	2·48	2·43	2·30	2·40
Ash (pure) } in dry matter	1·95	1·67	1·86	1·81	1·83	1·98	1·72	1·91
Composition of the Grain-Ash, per cent.								
Ferric oxide	1·04	0·79	0·80	0·83	0·64	1·20	0·79	0·75
Lime	3·22	3·46	3·63	3·51	3·51	3·75	3·36	3·57
Magnesia	10·80	10·31	10·70	10·67	12·70	9·34	10·16	10·36
Potash	30·60	35·56	33·19	32·64	28·10	35·88	35·75	34·66
Soda	0·81	0·43	0·28	0·66	0·48	0·78	0·53	0·36
Phosphoric anhydride	51·33	45·87	49·24	49·57	52·92	44·65	46·11	47·53
Sulphuric anhydride	0·78	2·70	1·54	1·46	0·61	2·45	2·23	1·58
Chlorine	trace	0·03	0·03	0·03	trace	0·17	0·45	0·28
Silica	1·42	0·86	0·60	0·64	1·04	1·82	0·72	0·97
Total	100·00	100·01	100·01	100·01	100·00	100·00	100·10	100·06
Deduct O = Cl	—	0·01	0·01	0·01	—	0·04	0·10	0·06
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Composition of the Straw, per cent.								
Dry matter	82·81	83·90	85·66	84·86	83·28	80·94	84·32	83·11
Nitrogen } in dry matter	0·82	0·85	0·78	0·74	0·89	1·29	0·56	0·62
Ash (pure) } in dry matter	5·43	5·83	5·30	5·42	5·60	5·86	4·54	5·61
Composition of the Straw-Ash, per cent.								
Ferric oxide	0·56	0·78	0·43	0·52	0·75	1·20	0·38	0·29
Lime	5·20	7·00	6·19	5·96	5·60	4·90	5·70	4·66
Magnesia	1·42	2·16	2·18	2·36	1·61	1·32	1·74	1·27
Potash	13·62	14·81	17·43	17·04	10·53	16·89	23·40	22·05
Soda	0·74	1·84	1·73	1·49	1·31	0·87	0·51	0·86
Phosphoric anhydride	3·23	2·71	3·47	3·63	2·50	4·34	2·14	2·10
Sulphuric anhydride	3·08	3·55	4·16	3·27	2·56	3·25	4·77	4·48
Chlorine	1·91	3·30	3·74	4·12	1·54	2·51	5·06	4·52
Silica	70·67	64·59	61·51	62·54	73·96	65·29	57·44	60·79
Total	100·43	100·74	100·84	100·93	100·36	100·57	101·14	101·02
Deduct O = Cl	0·43	0·74	0·84	0·93	0·36	0·57	1·14	1·02
Total	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Straw, grown at Rothamsted, year after year on the same Land.

Composition of the Ash (excluding Sand and Charcoal), of the Grain, and Straw, for the Consecutive Seasons, 1848–1863.

Plot 10a.—*Ammonium-Salts alone, every year.*

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
53·4	75·9	67·6	44·2	40·9	44·2	56·2	74·3	57·2	Grain to 100 straw.
55·6	58·0	59·6	51·5	49·5	55·0	56·5	62·6	57·1	Wt. per bushel of grain, lbs.
									Composition of the Grain, per cent.
83·98	84·93	83·92	82·37	85·03	84·85	83·56	84·80	83·92	Dry matter.
2·23	2·08	2·23	2·30	2·24	2·08	1·89	1·70	2·15	Nitrogen } in dry matter.
1·85	1·63	1·90	1·86	2·12	2·00	1·84	1·56	1·80	Ash (pure) } in dry matter.
									Composition of the Grain-Ash, per cent.
0·59	1·27	0·63	0·98	1·86	0·69	1·10	0·59	0·91	Ferric oxide.
3·61	4·38	4·05	3·64	3·41	3·47	3·54	3·85	3·62	Lime.
11·41	11·65	10·52	11·23	9·14	9·98	10·73	11·20	10·68	Magnesia.
31·86	31·58	33·52	32·69	34·82	35·54	34·17	34·42	33·43	Potash.
0·37	0·40	0·37	0·73	0·58	0·50	0·92	0·54	0·55	Soda.
50·05	46·99	46·69	47·17	43·35	44·62	44·31	46·02	47·28	Phosphoric anhydride.
1·00	2·12	2·78	2·36	3·67	2·63	2·91	2·37	2·07	Sulphuric anhydride.
none	0·13	0·55	0·04	0·86	1·14	0·67	0·19	0·28	Chlorine.
1·11	1·51	1·01	1·17	2·60	1·68	1·80	0·86	1·24	Silica.
100·00	100·03	100·12	100·01	100·19	100·25	100·15	100·04	100·06	Total.
—	0·03	0·12	0·01	0·19	0·25	0·15	0·04	0·06	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.
									Composition of the Straw, per cent.
83·34	84·96	85·36	85·24	84·80	84·71	83·37	84·17	84·11	Dry matter.
0·50	0·56	0·63	0·64	0·55	0·71	0·58	0·35	0·67	Nitrogen } in dry matter.
4·58	3·98	4·61	4·29	8·08	5·97	5·45	5·40	5·32	Ash (pure) } in dry matter.
									Composition of the Straw-Ash, per cent.
0·71	1·05	0·55	0·90	1·09	0·19	0·45	0·22	0·63	Ferric oxide.
5·57	7·79	8·64	8·37	3·32	5·62	5·78	6·92	6·07	Lime.
1·21	1·88	2·44	2·03	1·13	1·91	2·05	1·74	1·78	Magnesia.
13·95	17·50	17·34	13·29	15·37	22·20	13·65	14·25	16·46	Potash.
1·71	0·81	1·16	1·88	0·13	1·81	1·02	0·52	1·15	Soda.
3·33	2·99	3·15	3·54	4·29	2·90	3·35	1·73	3·09	Phosphoric anhydride.
3·98	4·23	7·79	4·55	2·96	4·88	3·44	3·88	4·05	Sulphuric anhydride.
1·59	2·73	2·85	1·78	1·54	3·83	1·68	3·55	2·89	Chlorine.
66·31	61·64	56·73	64·06	70·52	57·52	68·96	67·99	64·53	Silica.
100·36	100·62	100·65	100·40	100·35	100·86	100·38	100·80	100·65	Total.
0·36	0·62	0·65	0·40	0·35	0·86	0·38	0·80	0·65	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table IV.—General Characters of the Produce, and amounts of 100° C.), of Grain, Straw, and Total Produce, in

Plot 2.—Farmyard Manure, every year.

Harvests	1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw	56·0	68·3	57·3	66·2	49·6	33·2	60·1	58·2
Weight per bushel of grain, lbs.	58·2	63·8	61·9	63·6	58·2	51·1	62·5	62·0
Per 1000 dry matter of grain. Fresh produce	1255	1209	1192	1184	1201	1246	1164	1195
Per 1000 dry matter of grain. Nitrogen	18·9	15·8	16·6	15·7	20·2	17·6	17·0	21·9
Ash-constituents, per 1000 dry matter of grain. Ferric oxide	0·25	0·15	0·24	0·17	0·19	0·18	0·12	0·14
Lime	0·49	0·49	0·57	0·55	0·55	0·57	0·49	0·52
Magnesia	2·19	2·03	2·27	2·15	2·53	2·23	2·24	2·29
Potash	6·11	6·37	6·41	6·25	5·38	7·79	6·34	6·43
Soda	0·11	0·13	0·16	0·10	0·09	0·12	0·10	0·18
Phosphoric anhydride	10·67	9·70	10·32	9·79	10·83	10·33	10·36	11·08
Sulphuric anhydride	0·11	0·29	0·29	0·18	0·03	0·52	0·09	0·01
Chlorine	0·01	0·01	none	trace	trace	0·02	trace	none
Silica	0·32	0·10	0·19	0·13	0·20	0·20	0·10	0·14
Total	20·26	19·27	20·45	19·32	19·80	21·96	19·84	20·79
Deduct O = Cl	—	—	—	—	—	—	—	—
Total	20·26	19·27	20·45	19·32	19·80	21·96	19·84	20·79
Per 1000 dry matter of straw. Fresh produce	1228	1212	1212	1171	1216	1239	1178	1190
Per 1000 dry matter of straw. Nitrogen	4·9	4·5	5·0	4·8	4·6	7·3	3·5	4·3
Ash-constituents, per 1000 dry matter of straw. Ferric oxide	0·38	0·52	0·38	0·30	0·59	0·29	0·16	0·21
Lime	2·60	3·38	3·27	2·79	2·73	2·14	2·60	2·64
Magnesia	0·83	1·17	1·34	1·24	1·07	0·91	0·96	0·96
Potash	10·22	11·41	11·96	11·80	9·06	13·38	9·64	15·54
Soda	0·18	0·36	0·59	0·36	0·42	0·34	0·23	0·33
Phosphoric anhydride	2·93	1·98	2·67	3·07	2·27	4·12	1·49	2·88
Sulphuric anhydride	1·90	2·18	2·27	2·22	1·82	2·36	2·26	1·75
Chlorine	1·33	1·95	2·39	1·85	1·31	1·77	1·59	3·71
Silica	44·88	43·92	38·40	43·39	51·47	41·50	30·43	46·78
Total	65·25	66·87	63·26	67·02	70·74	66·81	49·36	74·80
Deduct O = Cl	0·30	0·44	0·54	0·42	0·30	0·40	0·36	0·84
Total	64·95	66·43	62·72	66·60	70·44	66·41	49·00	73·96
Per 1000 dry matter of total produce (grain and straw). Fresh produce	1237	1210	1205	1176	1211	1241	1173	1192
Per 1000 dry matter of total produce (grain and straw). Nitrogen	9·9	9·1	10·0	9·1	9·8	9·9	8·6	10·8
Ash-constituents, per 1000 dry matter of total produce (grain and straw.) Ferric oxide	0·33	0·37	0·33	0·25	0·46	0·26	0·15	0·18
Lime	1·85	2·20	2·28	1·91	2·00	1·75	1·80	1·96
Magnesia	1·31	1·52	1·68	1·60	1·56	1·23	1·44	1·45
Potash	8·76	9·36	9·91	9·60	7·83	11·99	8·39	12·20
Soda	0·16	0·27	0·43	0·25	0·31	0·29	0·18	0·27
Phosphoric anhydride	5·67	5·12	5·49	5·73	5·13	5·67	4·84	5·89
Sulphuric anhydride	1·27	1·41	1·54	1·41	1·22	1·90	1·44	1·11
Chlorine	0·87	1·16	1·51	1·12	0·87	1·34	0·99	2·35
Silica	29·09	26·11	24·32	26·26	34·31	31·24	18·96	29·67
Total	49·31	47·52	47·49	48·13	53·69	55·67	38·19	54·98
Deduct O = Cl	0·20	0·26	0·34	0·25	0·20	0·30	0·22	0·53
Total	49·11	47·26	47·15	47·88	53·49	55·37	37·97	54·45

Straw, grown at Rothamsted, year after year on the same Land.

Nitrogen, Ash-Constituents, and Total Ash (pure), *per* 1000 *Dry Matter* (at sixteen consecutive Seasons, 1848–1863.

Plot 2.—*Farmyard Manure, every year.*

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
32·8	77·9	65·5	47·1	54·2	71·0	58·3	67·5	58·6	Grain to 100 straw.
58·6	60·4	62·6	56·5	55·5	60·5	61·0	63·1	60·0	Wt. per bushel of grain, lbs.
1211	1124	1197	1209	1169	1181	1201	1182	1194	Fresh produce.
18·9	19·7	19·1	20·9	20·0	19·5	15·7	15·2	18·3	Nitrogen.
0·17	0·20	0·19	0·16	0·22	0·11	0·15	0·08	0·16	Ferric oxide.
0·50	0·56	0·53	0·50	0·60	0·54	0·50	0·43	0·52	Lime.
2·32	2·32	2·28	2·36	2·18	2·21	2·22	2·12	2·24	Magnesia.
5·80	5·79	6·52	6·58	7·27	7·12	6·37	5·85	6·35	Potash.
0·08	0·15	0·06	0·11	0·14	0·14	0·13	0·12	0·12	Soda.
10·73	10·18	10·61	11·10	10·65	11·05	10·28	9·65	10·44	Phosphoric anhydride.
0·05	0·09	0·15	0·11	0·19	0·22	0·10	0·17	0·15	Sulphuric anhydride.
0·01	trace	0·01	trace	0·02	none	none	trace	0·01	Chlorine.
0·15	0·10	0·10	0·17	0·27	0·11	0·16	0·12	0·15	Silica.
19·81	19·39	20·45	21·09	21·54	21·50	19·91	18·54	20·14	Total.
—	—	—	—	—	—	—	—	—	Deduct O = Cl.
19·81	19·39	20·45	21·09	21·54	21·50	19·91	18·54	20·14	Total.
1204	1185	1174	1181	1176	1165	1192	1184	1193	Fresh produce.
3·8	3·9	4·7	4·0	5·6	4·3	3·7	2·5	4·4	Nitrogen.
0·32	0·44	0·28	0·38	0·66	0·16	0·26	0·12	0·33	Ferric oxide.
2·61	2·98	2·59	2·85	2·53	2·44	2·16	2·43	2·66	Lime.
1·03	0·88	1·09	0·83	0·84	0·86	0·90	0·91	0·98	Magnesia.
9·60	10·96	13·92	11·63	13·21	18·37	9·73	11·53	11·91	Potash.
0·35	0·24	0·31	0·34	0·40	0·51	0·36	none	0·32	Soda.
2·25	1·89	2·19	2·19	3·20	2·59	2·20	2·02	2·45	Phosphoric anhydride.
1·72	1·46	2·28	1·27	2·01	2·51	1·53	1·63	1·92	Sulphuric anhydride.
1·50	2·19	3·09	1·74	1·54	3·57	1·24	2·32	2·06	Chlorine.
46·64	33·98	39·10	41·57	55·05	41·48	48·84	43·74	43·08	Silica.
66·02	55·02	64·85	62·80	79·44	72·49	67·22	64·70	65·71	Total.
0·34	0·49	0·69	0·39	0·35	0·81	0·28	0·52	0·46	Deduct O = Cl.
65·68	54·53	64·16	62·41	79·09	71·68	66·94	64·18	65·25	Total.
1206	1178	1183	1190	1174	1172	1195	1183	1193	Fresh produce.
9·0	10·9	10·3	9·3	10·7	10·5	8·1	7·6	9·5	Nitrogen.
0·27	0·34	0·24	0·31	0·50	0·14	0·22	0·10	0·27	Ferric oxide.
1·89	1·91	1·78	2·11	1·85	1·66	1·55	1·63	1·87	Lime.
1·48	1·51	1·56	1·31	1·31	1·42	1·38	1·39	1·45	Magnesia.
8·29	8·68	11·03	10·04	11·12	13·73	8·50	9·24	9·85	Potash.
0·26	0·20	0·21	0·26	0·31	0·36	0·28	0·05	0·25	Soda.
5·17	5·55	5·48	5·00	5·83	6·07	5·16	5·10	5·40	Phosphoric anhydride.
1·14	0·85	1·45	0·91	1·37	1·56	1·01	1·04	1·27	Sulphuric anhydride.
0·99	1·22	1·88	1·19	1·01	2·10	0·78	1·38	1·30	Chlorine.
20·64	19·04	23·86	28·54	35·72	24·44	30·99	26·15	27·23	Silica.
50·13	39·30	47·49	49·67	59·02	51·48	49·87	46·08	48·89	Total.
0·23	0·27	0·42	0·27	0·23	0·47	0·18	0·31	0·29	Deduct O = Cl.
49·90	39·03	47·07	49·40	58·79	51·01	49·69	45·77	48·60	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table V.—General Characters of the Produce, and amounts of 100° C.), of Grain, Straw, and Total Produce, in

Plot 3.—Unmanured, every year.

Harvests		1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw		55·6	76·1	58·2	66·6	53·9	25·4	63·6	60·0
Weight per bushel of grain, lbs.		57·3	61·4	60·6	61·1	56·8	45·9	60·6	59·2
Per 1000 dry matter of grain.	Fresh produce	1244	1216	1193	1186	1211	1247	1181	1179
	Nitrogen	21·7	17·3	18·3	16·7	20·8	20·9	19·2	21·4
Ash-constituents, per 1000 dry matter of grain.	Ferric oxide	0·28	0·20	0·26	0·14	0·22	0·30	0·12	0·12
	Lime	0·57	0·59	0·60	0·58	0·58	0·73	0·52	0·53
	Magnesia	2·07	1·83	1·99	1·97	2·36	2·43	2·04	2·01
	Potash	6·25	6·65	6·65	6·75	6·01	8·38	6·67	6·86
	Soda	0·13	0·08	0·18	0·09	0·13	0·13	0·14	0·10
	Phosphoric anhydride	10·29	8·98	10·02	9·53	10·50	10·75	9·64	10·27
	Sulphuric anhydride	0·16	0·34	0·23	0·22	0·20	0·57	0·31	0·13
	Chlorine	trace	trace	0·01	0·01	0·01	0·04	trace	0·01
	Silica	0·27	0·14	0·23	0·14	0·27	0·30	0·09	0·19
	Total	20·02	18·81	20·17	19·43	20·28	23·63	19·53	20·22
	Deduct O = Cl	—	—	—	—	—	0·01	—	—
	Total	20·02	18·81	20·17	19·43	20·28	23·62	19·53	20·22
Per 1000 dry matter of straw.	Fresh produce	1234	1218	1211	1186	1194	1226	1201	1207
	Nitrogen	5·3	4·9	5·3	5·7	5·7	8·5	3·9	4·8
Ash-constituents, per 1000 dry matter of straw.	Ferric oxide	0·76	0·70	0·33	0·52	0·73	0·59	0·25	0·35
	Lime	1·88	2·00	1·91	1·86	1·77	2·77	2·69	1·94
	Magnesia	1·50	2·40	2·27	1·83	1·85	1·08	0·94	1·35
	Potash	9·04	10·43	10·64	11·02	7·43	8·94	9·22	12·17
	Soda	0·23	0·57	0·34	0·22	0·36	0·45	0·26	0·29
	Phosphoric anhydride	2·83	2·09	3·31	3·51	2·52	3·74	1·65	2·30
	Sulphuric anhydride	1·39	1·99	2·19	2·37	1·67	2·09	2·46	1·84
	Chlorine	0·97	1·31	1·44	1·45	0·76	0·70	1·30	2·04
	Silica	49·28	49·05	48·22	43·00	53·51	42·54	33·17	51·14
	Total	67·88	70·54	70·65	65·78	70·60	62·90	51·94	73·42
	Deduct O = Cl	0·22	0·29	0·32	0·33	0·17	0·16	0·29	0·46
	Total	67·66	70·25	70·33	65·45	70·43	62·74	51·65	72·96
Per 1000 dry matter of total produce (grain and straw).	Fresh produce	1238	1217	1204	1186	1209	1230	1193	1197
	Nitrogen	11·2	10·3	10·1	10·1	11·0	11·0	9·9	11·1
Ash-constituents, per 1000 dry matter of total produce (grain and straw).	Ferric oxide	0·58	0·49	0·31	0·37	0·55	0·53	0·20	0·26
	Lime	1·42	1·39	1·42	1·35	1·36	2·37	1·84	1·40
	Magnesia	1·70	2·15	2·17	1·89	2·03	1·35	1·37	1·60
	Potash	8·05	8·79	9·16	9·31	6·93	8·83	8·22	10·15
	Soda	0·19	0·36	0·28	0·17	0·28	0·38	0·22	0·22
	Phosphoric anhydride	5·49	5·07	5·80	5·92	5·31	5·14	4·78	5·34
	Sulphuric anhydride	0·95	1·28	1·46	1·51	1·16	1·78	1·61	1·19
	Chlorine	0·63	0·74	0·91	0·87	0·50	0·57	0·79	1·27
	Silica	31·86	27·88	30·38	25·87	34·90	34·10	20·18	31·75
	Total	50·87	48·15	51·89	47·26	53·02	55·05	39·21	53·18
	Deduct O = Cl	0·14	0·16	0·21	0·20	0·11	0·13	0·18	0·29
	Total	50·73	47·99	51·68	47·06	52·91	54·92	39·03	52·89

Straw, grown at Rothamsted, year after year on the same Land.

Nitrogen, Ash-Constituents, and Total Ash (pure), *per* 1000 *Dry Matter* (at sixteen consecutive Seasons, 1848–1863.

Plot 3.—Unmanured, every year.

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
57·3	78·3	68·3	48·3	50·6	58·7	58·2	70·4	59·5	Grain to 100 straw.
54·3	58·3	60·4	52·5	52·6	57·4	57·8	62·7	57·4	Wt. per bushel of grain, lbs.
1217	1178	1197	1214	1204	1176	1215	1191	1200	Fresh produce.
19·1	19·1	18·6	19·6	19·2	20·4	17·6	16·5	19·0	Nitrogen.
0·18	0·21	0·21	0·20	0·35	0·23	0·27	0·10	0·20	Ferric oxide.
0·52	0·65	0·56	0·57	0·59	0·59	0·51	0·52	0·57	Lime.
2·19	2·08	2·12	2·28	1·98	2·09	2·08	2·12	2·08	Magnesia.
6·23	6·16	6·61	6·64	7·26	7·54	6·56	6·28	6·62	Potash.
0·13	0·08	0·10	0·09	0·16	0·12	0·24	0·15	0·13	Soda.
10·72	9·62	10·27	10·52	10·25	10·39	10·05	10·03	10·03	Phosphoric anhydride.
0·22	0·25	0·13	0·26	0·48	0·36	0·33	0·13	0·25	Sulphuric anhydride.
trace	0·01	none	0·02	0·05	0·03	0·02	none	0·01	Chlorine.
0·20	0·19	0·20	0·22	0·51	0·55	0·24	0·12	0·22	Silica.
20·39	19·25	20·20	20·80	21·63	21·90	20·30	19·45	20·11	Total.
—	—	—	—	0·01	0·01	—	—	—	Deduct O = Cl.
20·39	19·25	20·20	20·80	21·62	21·89	20·30	19·45	20·11	Total.
1188	1185	1171	1183	1169	1172	1196	1190	1196	Fresh produce.
4·1	4·5	4·5	5·1	5·8	6·3	4·4	3·3	5·0	Nitrogen.
0·69	0·79	0·37	0·49	1·10	0·22	0·47	0·24	0·53	Ferric oxide.
2·70	1·39	3·38	3·23	3·42	2·93	2·58	3·13	2·48	Lime.
0·99	1·69	1·21	0·85	0·86	0·99	0·89	1·06	1·35	Magnesia.
6·96	7·26	9·59	6·98	9·61	14·16	7·53	9·27	9·30	Potash.
0·35	1·02	0·34	0·34	0·28	0·24	0·24	0·18	0·35	Soda.
2·35	1·69	1·67	1·95	2·90	2·52	2·11	2·25	2·42	Phosphoric anhydride.
1·86	1·32	2·45	1·82	1·99	2·77	1·81	2·03	2·00	Sulphuric anhydride.
0·86	1·04	1·44	0·75	0·95	2·19	0·83	1·45	1·21	Chlorine.
42·11	32·19	35·31	37·02	62·40	42·94	52·59	51·92	45·00	Silica.
56·87	48·39	55·76	53·43	83·51	68·96	69·05	71·53	64·64	Total.
0·20	0·23	0·33	0·17	0·21	0·49	0·19	0·33	0·27	Deduct O = Cl.
56·67	48·16	55·43	53·26	83·30	68·47	68·86	71·20	64·37	Total.
1198	1182	1182	1193	1181	1173	1203	1190	1198	Fresh produce.
9·5	10·9	10·1	9·8	10·2	11·5	9·2	8·7	10·3	Nitrogen.
0·51	0·54	0·31	0·39	0·85	0·22	0·39	0·18	0·41	Ferric oxide.
1·92	1·07	2·25	2·38	2·49	2·07	1·83	2·05	1·77	Lime.
1·42	1·86	1·57	1·31	1·23	1·40	1·33	1·50	1·62	Magnesia.
6·70	6·77	8·40	6·87	8·83	11·72	7·18	8·04	8·30	Potash.
0·27	0·60	0·24	0·26	0·24	0·19	0·24	0·17	0·27	Soda.
5·35	5·19	5·12	4·70	5·32	5·42	5·00	5·46	5·26	Phosphoric anhydride.
1·27	0·84	1·52	1·32	1·49	1·89	1·27	1·25	1·35	Sulphuric anhydride.
0·55	0·59	0·87	0·51	0·66	1·39	0·53	0·85	0·76	Chlorine.
27·09	18·09	21·24	25·24	42·02	27·29	33·53	30·53	28·32	Silica.
45·08	35·55	41·52	42·98	63·13	51·59	51·30	50·03	48·06	Total.
0·13	0·13	0·20	0·11	0·15	0·31	0·13	0·19	0·17	Deduct O = Cl.
44·95	35·42	41·32	42·87	62·98	51·28	51·17	49·84	47·89	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table VI.—General Characters of the Produce, Amounts of Nitrogen, Grain, Straw, and Total Produce, in sixteen

Plot 10a.—Ammonium-Salts alone, every year.

Harvests		1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw		56·3	75·1	55·7	64·0	47·3	31·3	61·5	51·2
Weight per bushel of grain, lbs.		58·1	62·3	60·2	61·9	55·9	48·6	60·5	57·1
Per 1000 dry matter of grain.	Fresh produce	1232	1209	1186	1184	1193	1242	1178	1188
	Nitrogen	24·2	19·5	21·3	21·5	24·8	24·3	23·0	24·0
Ash-constituents, per 1000 dry matter of grain.	Ferric oxide	0·20	0·13	0·15	0·15	0·12	0·24	0·14	0·14
	Lime	0·63	0·58	0·68	0·64	0·64	0·74	0·58	0·68
	Magnesia	2·11	1·72	1·99	1·93	2·33	1·85	1·74	1·97
	Potash	5·98	5·93	6·18	5·89	5·15	7·09	6·15	6·61
	Soda	0·16	0·07	0·05	0·12	0·09	0·15	0·09	0·07
	Phosphoric anhydride	10·03	7·66	9·16	8·96	9·69	8·82	7·93	9·06
	Sulphuric anhydride	0·15	0·45	0·29	0·26	0·11	0·49	0·38	0·30
	Chlorine	trace	0·01	0·01	0·01	trace	0·02	0·08	0·05
	Silica	0·28	0·14	0·11	0·11	0·19	0·36	0·12	0·18
	Total	19·54	16·69	18·62	18·07	18·32	19·77	17·21	19·06
	Deduct O = Cl	—	—	—	—	—	0·01	0·02	0·01
	Total	19·54	16·69	18·62	18·07	18·32	19·76	17·19	19·05
Per 1000 dry matter of straw.	Fresh produce	1208	1192	1167	1178	1200	1236	1186	1204
	Nitrogen	8·2	8·5	7·8	7·4	8·9	12·9	5·6	6·2
Ash-constituents, per 1000 dry matter of straw.	Ferric oxide	0·30	0·45	0·23	0·29	0·42	0·70	0·17	0·17
	Lime	2·83	4·08	3·28	3·23	3·13	2·87	2·59	2·62
	Magnesia	0·77	1·26	1·16	1·28	0·90	0·78	0·79	0·71
	Potash	7·40	8·62	9·23	9·23	5·89	9·89	10·63	12·36
	Soda	0·40	1·07	0·91	0·80	0·74	0·51	0·23	0·48
	Phosphoric anhydride	1·76	1·58	1·84	1·97	1·40	2·54	0·97	1·17
	Sulphuric anhydride	1·67	2·07	2·20	1·78	1·43	1·90	2·16	2·52
	Chlorine	1·04	1·92	1·98	2·23	0·87	1·47	2·30	2·54
	Silica	38·41	37·63	32·58	33·88	41·39	38·24	26·09	34·09
	Total	54·58	58·68	53·41	54·69	56·17	58·90	45·93	56·66
	Deduct O = Cl	0·23	0·43	0·44	0·51	0·20	0·33	0·52	0·57
	Total	54·35	58·25	52·97	54·18	55·97	58·57	45·41	56·09
Per 1000 dry matter of total produce (grain and straw).	Fresh produce	1216	1199	1174	1180	1198	1237	1183	1198
	Nitrogen	13·9	13·2	12·6	12·9	14·0	15·6	12·3	12·3
Ash-constituents, per 1000 dry matter of total produce (grain and straw.)	Ferric oxide	0·27	0·32	0·20	0·23	0·32	0·59	0·16	0·16
	Lime	2·04	2·59	2·36	2·22	2·33	2·37	1·82	1·95
	Magnesia	1·25	1·46	1·45	1·53	1·36	1·03	1·15	1·14
	Potash	6·89	7·48	8·15	7·93	5·65	9·23	8·91	10·40
	Soda	0·32	0·65	0·61	0·54	0·53	0·43	0·18	0·34
	Phosphoric anhydride	4·70	4·16	4·44	4·69	4·08	4·03	3·63	3·86
	Sulphuric anhydride	1·13	1·38	1·52	1·19	1·00	1·56	1·48	1·76
	Chlorine	0·67	1·11	1·28	1·37	0·59	1·13	1·45	1·69
	Silica	24·84	21·67	21·08	20·74	28·10	29·23	16·16	22·52
	Total	42·11	40·82	41·09	40·44	43·96	49·60	34·94	43·82
	Deduct O = Cl	0·15	0·25	0·29	0·31	0·14	0·26	0·32	0·38
	Total	41·96	40·57	40·80	40·13	43·82	49·34	34·62	43·44

Straw, grown at Rothamsted, year after year on the same Land.

Ash-Constituents, and Total Ash (pure), *per* 1000 *Dry Matter* (at 100° C.), of consecutive Seasons, 1848–1863.

Plot 10*a*.—*Ammonium-Salts alone, every year.*

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
53·4	75·9	67·6	44·2	40·9	44·2	56·2	74·3	57·2	Grain to 100 straw.
56·6	58·0	59·6	51·5	49·5	55·0	56·5	62·6	57·1	Wt. per bushel of grain, lbs.
1191	1178	1191	1214	1175	1178	1197	1179	1191	Fresh produce.
22·3	20·8	22·3	23·0	22·4	20·8	18·9	17·0	21·5	Nitrogen.
0·11	0·21	0·12	0·18	0·39	0·14	0·20	0·09	0·16	Ferric oxide.
0·67	0·72	0·77	0·68	0·72	0·69	0·65	0·60	0·65	Lime.
2·11	1·90	1·99	2·09	1·94	2·00	1·98	1·75	1·93	Magnesia.
5·88	5·16	6·35	6·09	7·38	7·12	6·30	5·37	6·02	Potash.
0·07	0·07	0·07	0·14	0·12	0·10	0·17	0·09	0·10	Soda.
9·25	7·67	8·85	8·78	9·18	8·94	8·17	7·18	8·54	Phosphoric anhydride.
0·19	0·34	0·53	0·44	0·76	0·53	0·54	0·37	0·37	Sulphuric anhydride.
none	0·02	0·11	0·01	0·18	0·23	0·12	0·03	0·04	Chlorine.
0·20	0·25	0·19	0·22	0·55	0·34	0·33	0·13	0·21	Silica.
18·48	16·34	18·96	18·63	21·22	20·09	18·46	15·61	18·02	Total.
—	—	0·02	—	0·04	0·05	0·03	0·01	0·01	Deduct O = Cl.
18·48	16·34	18·96	18·63	21·18	20·04	18·43	15·60	18·01	Total.
1201	1177	1171	1173	1180	1180	1199	1188	1189	Fresh produce.
5·0	5·6	6·3	6·4	5·5	7·1	5·8	3·5	6·7	Nitrogen.
0·32	0·42	0·26	0·39	0·88	0·12	0·24	0·12	0·33	Ferric oxide.
2·55	3·10	3·98	3·59	2·68	3·36	3·15	3·74	3·18	Lime.
0·55	0·75	1·13	0·87	0·91	1·14	1·12	0·94	0·94	Magnesia.
6·39	6·97	8·00	5·69	12·42	13·24	7·44	7·70	8·71	Potash.
0·79	0·32	0·54	0·81	0·10	1·08	0·55	0·29	0·60	Soda.
1·53	1·19	1·45	1·52	3·47	1·73	1·83	0·93	1·63	Phosphoric anhydride.
1·82	1·69	3·60	1·95	2·39	2·91	1·88	2·09	2·10	Sulphuric anhydride.
0·73	1·09	1·31	0·76	1·25	2·29	0·92	1·92	1·57	Chlorine.
31·27	24·53	26·16	27·45	57·01	34·32	37·59	36·74	34·49	Silica.
45·95	40·06	46·43	43·03	81·11	60·19	54·72	54·47	53·55	Total.
0·16	0·25	0·30	0·17	0·28	0·51	0·20	0·43	0·35	Deduct O = Cl.
45·79	39·81	46·13	42·86	80·83	59·68	54·52	54·04	53·20	Total.
1197	1177	1179	1185	1178	1180	1199	1184	1190	Fresh produce.
11·0	12·2	12·7	11·4	10·4	11·3	10·5	9·3	12·1	Nitrogen.
0·25	0·33	0·20	0·32	0·74	0·12	0·23	0·11	0·27	Ferric oxide.
1·89	2·07	2·70	2·71	2·11	2·54	2·25	2·40	2·26	Lime.
1·10	1·24	1·47	1·24	1·21	1·40	1·43	1·28	1·30	Magnesia.
6·21	6·19	7·35	5·81	10·95	11·36	7·03	6·70	7·74	Potash.
0·53	0·21	0·35	0·61	0·11	0·78	0·42	0·20	0·42	Soda.
4·23	3·99	4·41	3·70	5·13	3·95	4·11	3·61	4·14	Phosphoric anhydride.
1·25	1·11	2·37	1·50	1·92	2·18	1·39	1·35	1·47	Sulphuric anhydride.
0·47	0·63	0·83	0·54	0·94	1·66	0·63	1·11	1·01	Chlorine.
20·40	14·06	15·80	19·30	40·58	23·88	24·17	21·07	22·03	Silica.
36·33	29·83	35·48	35·73	63·69	47·87	41·66	37·83	40·64	Total.
0·11	0·14	0·19	0·12	0·21	0·37	0·14	0·25	0·23	Deduct O = Cl.
36·22	29·69	35·29	35·61	63·48	47·50	41·52	37·58	40·41	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table VII.—General Characters of the Produce, and Quantities of (pure), *per Acre*, in Grain, Straw, and Total

Plot 2.—Farmyard Manure, every year.

Harvests		1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw		56·0	68·3	57·3	66·2	49·6	33·2	60·1	58·2
Weight per bushel of grain, lbs.		58·2	63·8	61·9	63·6	58·2	51·1	62·5	62·0
Produce of grain, per acre, lbs.	Fresh produce	1705	2068	1861	2049	1716	1120	2675	2237
	Dry matter	1359	1712	1561	1731	1429	899	2298	1872
	Nitrogen	25·7	27·0	29·0	27·2	28·9	15·8	39·1	41·0
Ash-constituents of grain, per acre, lbs.	Ferric oxide	0·34	0·25	0·37	0·29	0·27	0·16	0·28	0·27
	Lime	0·66	0·83	0·90	0·96	0·79	0·51	1·12	0·97
	Magnesia	2·97	3·48	3·53	3·72	3·61	2·00	5·14	4·29
	Potash	8·30	10·91	10·01	10·82	7·70	7·00	14·58	12·03
	Soda	0·16	0·22	0·26	0·17	0·13	0·11	0·22	0·33
	Phosphoric anhydride	14·49	16·60	16·11	16·95	15·47	9·29	23·80	20·74
	Sulphuric anhydride	0·15	0·50	0·45	0·31	0·04	0·47	0·21	0·01
	Chlorine	0·02	0·01	none	trace	trace	0·02	0·01	none
	Silica	0·43	0·18	0·29	0·22	0·28	0·18	0·23	0·27
	Total	27·52	32·98	31·92	33·44	28·29	19·74	45·59	38·91
	Deduct O = Cl	—	—	—	—	—	—	—	—
	Total	27·52	32·98	31·92	33·44	28·29	19·74	45·59	38·91
Produce of straw, per acre, lbs.	Fresh produce	3041	3029	3245	3094	3457	3372	4450	3845
	Dry matter	2477	2499	2677	2642	2842	2721	3778	3230
	Nitrogen	12·1	11·2	13·4	12·7	13·1	19·9	13·2	13·9
Ash-constituents of straw, per acre, lbs.	Ferric oxide	0·94	1·30	1·02	0·79	1·69	0·78	0·62	0·68
	Lime	6·45	8·43	8·76	7·38	7·76	5·83	9·83	8·53
	Magnesia	2·05	2·93	3·59	3·29	3·04	2·47	3·63	3·11
	Potash	25·31	28·52	31·98	31·16	25·76	36·39	36·41	50·20
	Soda	0·45	0·91	1·57	0·95	1·19	0·93	0·86	1·07
	Phosphoric anhydride	7·26	4·94	7·16	8·10	6·44	11·22	5·62	9·31
	Sulphuric anhydride	4·70	5·44	6·07	5·87	5·16	6·42	8·54	5·64
	Chlorine	3·30	4·88	6·41	4·88	3·72	4·83	6·00	11·98
	Silica	111·16	109·76	102·78	114·63	146·27	112·92	114·96	151·10
	Total	161·62	167·11	169·34	177·05	201·03	181·79	186·47	241·62
	Deduct O = Cl	0·74	1·09	1·45	1·11	0·84	1·08	1·36	2·70
	Total	160·88	166·02	167·89	175·94	200·19	180·71	185·11	238·92
Total produce (grain and straw), per acre, lbs.	Fresh produce	4746	5097	5106	5143	5173	4492	7125	6082
	Dry matter	3836	4211	4238	4373	4271	3620	6076	5102
	Nitrogen	37·8	38·2	42·4	39·9	42·0	35·7	52·3	54·9
Ash-constituents of total produce (grain and straw), per acre, lbs.	Ferric oxide	1·28	1·55	1·39	1·08	1·96	0·94	0·90	0·95
	Lime	7·11	9·26	9·66	8·34	8·55	6·34	10·95	9·50
	Magnesia	5·02	6·41	7·12	7·01	6·65	4·47	8·77	7·40
	Potash	33·61	39·43	41·99	41·98	33·46	43·39	50·99	62·23
	Soda	0·61	1·13	1·83	1·12	1·32	1·04	1·08	1·40
	Phosphoric anhydride	21·75	21·54	23·27	25·05	21·91	20·51	29·42	30·05
	Sulphuric anhydride	4·85	5·94	6·52	6·18	5·20	6·89	8·75	5·65
	Chlorine	3·32	4·89	6·41	4·88	3·72	4·85	6·01	11·98
	Silica	111·59	109·94	103·07	114·85	146·55	113·10	115·19	151·37
	Total	189·14	200·09	201·26	210·49	229·32	201·53	232·06	280·53
	Deduct O = Cl	0·74	1·09	1·45	1·11	0·84	1·08	1·36	2·70
	Total	188·40	199·00	199·81	209·38	228·48	200·45	230·70	277·83

Straw, grown at Rothamsted, year after year on the same Land.

Fresh Produce, Dry Matter, Nitrogen, Ash-Constituents, and Total Ash Produce, in sixteen consecutive Seasons, 1848–1863.

Plot 2.—Farmyard Manure, every year.

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
52·8	77·9	65·5	47·1	54·2	71·0	58·3	67·5	58·6	Grain to 100 straw.
58·6	60·4	62·6	56·5	55·5	60·5	61·0	63·1	60·0	Wt. per bushel of grain, lbs.
2277	2587	2512	2263	1864	2202	2447	2886	2154	Fresh produce.
1881	2212	2099	1872	1594	1864	2038	2442	1804	Dry matter.
35·6	43·6	40·1	39·1	31·9	36·3	32·0	37·1	33·1	Nitrogen.
0·32	0·45	0·39	0·31	0·35	0·19	0·31	0·20	0·30	Ferric oxide.
0·94	1·24	1·12	0·94	0·95	1·01	1·02	1·06	0·94	Lime.
4·36	5·13	4·79	4·42	3·48	4·13	4·52	5·17	4·04	Magnesia.
10·91	12·80	13·68	12·31	11·60	13·27	12·98	14·28	11·45	Potash.
0·16	0·33	0·12	0·21	0·23	0·26	0·27	0·30	0·22	Soda.
20·19	22·52	22·27	20·79	16·96	20·60	20·94	23·55	18·33	Phosphoric anhydride.
0·09	0·20	0·32	0·20	0·30	0·41	0·21	0·42	0·27	Sulphuric anhydride.
0·03	trace	0·03	trace	0·02	none	none	trace	0·01	Chlorine.
0·28	0·21	0·21	0·31	0·44	0·20	0·33	0·29	0·27	Silica.
37·28	42·88	42·93	39·49	34·33	40·07	40·58	45·27	36·33	Total.
0·01	—	0·01	—	—	—	—	—	—	Deduct O = Cl.
37·27	42·88	42·92	39·49	34·33	40·07	40·58	45·27	36·33	Total.
4217	3323	3837	4810	3440	3101	4195	4279	3677	Fresh produce.
3567	2805	3269	4073	2924	2662	3519	3613	3062	Dry matter.
13·6	10·9	15·4	16·3	16·4	11·4	13·0	9·0	13·5	Nitrogen.
1·15	1·23	0·92	1·55	1·93	0·44	0·91	0·42	1·02	Ferric oxide.
9·38	8·35	8·46	11·59	7·40	6·48	7·61	8·77	8·19	Lime.
3·71	2·47	3·55	3·38	2·45	2·29	3·16	3·27	3·03	Magnesia.
34·44	30·75	45·50	47·35	38·63	48·89	34·23	41·68	36·70	Potash.
1·25	0·68	1·03	1·36	1·17	1·37	1·27	none	1·00	Soda.
8·06	5·30	7·15	8·94	9·35	6·89	7·73	7·32	7·55	Phosphoric anhydride.
6·16	4·08	7·47	5·19	5·88	6·68	5·39	5·88	5·91	Sulphuric anhydride.
5·38	6·14	10·08	7·08	4·52	9·50	4·36	8·37	6·34	Chlorine.
167·29	95·32	127·84	169·33	160·96	110·42	171·89	158·03	132·79	Silica.
236·82	154·32	212·00	255·77	232·29	192·96	236·55	233·74	202·53	Total.
1·23	1·37	2·27	1·60	1·02	2·16	0·98	1·88	1·43	Deduct O = Cl.
235·59	152·95	209·73	254·17	231·27	190·80	235·57	231·86	201·10	Total.
6394	5910	6349	7073	5304	5303	6642	7165	5831	Fresh produce.
5468	5017	5368	5945	4518	4526	5557	6055	4886	Dry matter.
49·2	54·5	55·5	55·4	48·3	47·7	45·0	46·1	46·6	Nitrogen.
1·47	1·68	1·31	1·86	2·28	0·63	1·22	0·62	1·32	Ferric oxide.
10·32	9·59	9·58	12·53	8·35	7·49	8·63	9·33	9·13	Lime.
8·07	7·60	8·34	7·80	5·93	6·42	7·68	8·44	7·07	Magnesia.
45·35	43·55	59·18	59·66	50·23	62·16	47·21	55·96	48·15	Potash.
1·41	1·01	1·15	1·57	1·40	1·63	1·54	0·30	1·22	Soda.
28·25	27·82	29·42	29·73	26·31	27·49	28·67	30·87	26·38	Phosphoric anhydride.
6·25	4·28	7·79	5·39	6·18	7·09	5·60	6·30	6·18	Sulphuric anhydride.
5·41	6·14	10·11	7·08	4·54	9·50	4·36	8·37	6·35	Chlorine.
167·57	95·53	128·06	169·64	161·40	110·62	172·22	158·32	133·06	Silica.
274·11	197·20	254·93	295·28	266·62	233·03	277·13	279·01	238·86	Total.
1·24	1·37	2·28	1·60	1·02	2·16	0·98	1·88	1·43	Deduct O = Cl.
272·86	195·83	252·65	293·66	265·60	230·87	276·15	277·13	237·43	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table VIII.—General Characters of the Produce, and Quantities of (pure), *per Acre*, in Grain, Straw, and Total Pro-

Plot 3.—Unmanured, every year.

Harvests		1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw		55·6	76·1	58·2	66·6	53·9	25·4	63·6	60·0
Weight per bushel of grain, lbs.		57·3	61·4	60·6	61·1	56·6	45·9	60·6	59·2
Produce of grain, per acre, lbs.	Fresh produce	952	1229	1002	1083	860	359	1359	1072
	Dry matter	765	1011	840	913	710	288	1151	909
	Nitrogen	16·6	17·5	15·4	15·2	14·8	6·0	22·1	19·5
Ash-constituents of grain, per acre, lbs.	Ferric oxide	0·21	0·20	0·22	0·13	0·16	0·09	0·14	0·11
	Lime	0·44	0·60	0·50	0·53	0·41	0·21	0·60	0·49
	Magnesia	1·59	1·85	1·67	1·80	1·68	0·70	2·35	1·83
	Potash	4·78	6·72	5·58	6·16	4·27	2·41	7·68	6·23
	Soda	0·10	0·08	0·16	0·08	0·09	0·04	0·16	0·09
	Phosphoric anhydride	7·87	9·08	8·42	8·70	7·45	3·10	11·09	9·33
	Sulphuric anhydride	0·12	0·35	0·19	0·20	0·14	0·16	0·35	0·12
	Chlorine	trace	trace	0·01	0·01	0·01	0·01	0·01	0·01
	Silica	0·21	0·14	0·19	0·13	0·19	0·08	0·10	0·17
	Total	15·32	19·02	16·94	17·74	14·40	6·80	22·48	18·38
	Deduct O = Cl	—	—	—	—	—	—	—	—
	Total	15·32	19·02	16·94	17·74	14·40	6·80	22·48	18·38
Produce of straw, per acre, lbs.	Fresh produce	1712	1614	1719	1627	1597	1413	2137	1787
	Dry matter	1387	1325	1420	1372	1322	1153	1780	1480
	Nitrogen	7·4	6·5	7·5	7·8	7·5	9·8	6·9	7·1
Ash-constituents of straw, per acre, lbs.	Ferric oxide	1·05	0·93	0·47	0·71	0·96	0·67	0·45	0·52
	Lime	2·61	2·65	2·71	2·56	2·34	3·20	4·79	2·86
	Magnesia	2·08	3·18	3·23	2·51	2·45	1·24	1·67	2·00
	Potash	12·54	13·82	15·11	15·12	9·82	10·32	16·41	18·01
	Soda	0·32	0·75	0·48	0·30	0·48	0·52	0·47	0·44
	Phosphoric anhydride	3·93	2·77	4·70	4·82	3·33	4·31	2·93	3·41
	Sulphuric anhydride	1·92	2·64	3·11	3·25	2·21	2·41	4·38	2·72
	Chlorine	1·34	1·73	2·04	1·99	1·00	0·80	2·30	3·02
	Silica	68·35	64·99	68·48	58·99	70·74	49·05	59·05	75·69
	Total	94·14	93·46	100·33	90·25	93·33	72·52	92·45	108·67
	Deduct O = Cl	0·30	0·39	0·46	0·46	0·23	0·18	0·52	0·69
	Total	93·84	93·07	99·87	89·79	93·10	72·34	91·93	107·98
Total produce (grain and straw), per acre, lbs.	Fresh produce	2664	2843	2721	2710	2457	1772	3496	2859
	Dry matter	2152	2336	2260	2285	2032	1441	2931	2389
	Nitrogen	24·0	24·0	22·9	23·0	22·3	15·8	29·0	26·6
Ash-constituents of total produce (grain and straw), per acre, lbs.	Ferric oxide	1·26	1·13	0·69	0·84	1·12	0·76	0·59	0·63
	Lime	3·05	3·25	3·21	3·09	2·75	3·41	5·39	3·35
	Magnesia	3·67	5·03	4·90	4·31	4·13	1·94	4·02	3·83
	Potash	17·32	20·54	20·69	21·28	14·09	12·73	24·09	24·24
	Soda	0·42	0·83	0·64	0·38	0·57	0·56	0·63	0·53
	Phosphoric anhydride	11·80	11·85	13·12	13·52	10·78	7·41	14·02	12·74
	Sulphuric anhydride	2·04	2·99	3·30	3·45	2·35	2·57	4·73	2·84
	Chlorine	1·34	1·73	2·05	2·00	1·01	0·81	2·31	3·03
	Silica	68·56	65·13	68·67	59·12	70·93	49·13	59·15	75·86
	Total	109·46	112·48	117·27	107·99	107·73	79·32	114·93	127·05
	Deduct O = Cl	0·30	0·39	0·46	0·46	0·23	0·18	0·52	0·69
	Total	109·16	112·09	116·81	107·53	107·50	79·14	114·41	126·36

Straw, grown at Rothamsted, year after year on the same Land.

Fresh Produce, Dry Matter, Nitrogen, Ash-Constituents, and Total Ash duce, in sixteen consecutive Seasons, 1848–1863.

Plot 3.—*Unmanured, every year.*

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
57·3	78·3	68·3	48·3	50·6	58·7	58·2	70·4	59·5	Grain to 100 straw.
54·3	58·3	60·4	52·5	52·6	57·4	57·8	62·7	57·4	Wt. per bushel of grain, lbs.
992	1236	1141	1051	738	736	996	1127	990	Fresh produce.
733	1049	953	866	613	626	820	946	825	Dry matter.
14·0	20·0	17·7	17·0	11·8	12·8	14·4	15·6	15·7	Nitrogen.
0·13	0·22	0·20	0·17	0·21	0·14	0·22	0·09	0·16	Ferric oxide.
0·38	0·68	0·53	0·49	0·36	0·37	0·42	0·49	0·47	Lime.
1·61	2·18	2·02	1·98	1·21	1·31	1·70	2·01	1·72	Magnesia.
4·57	6·46	6·30	5·75	4·45	4·72	5·38	5·95	5·46	Potash.
0·10	0·09	0·09	0·07	0·10	0·07	0·20	0·14	0·10	Soda.
7·85	10·09	9·79	9·11	6·29	6·51	8·25	9·49	8·28	Phosphoric anhydride.
0·16	0·26	0·13	0·23	0·29	0·23	0·27	0·12	0·21	Sulphuric anhydride.
trace	0·01	none	0·02	0·03	0·02	0·01	none	0·01	Chlorine.
0·15	0·20	0·19	0·19	0·32	0·34	0·19	0·11	0·18	Silica.
14·95	20·19	19·25	18·01	13·26	13·71	16·64	18·40	16·59	Total.
—	—	—	—	0·01	—	—	—	—	Deduct O = Cl.
14·95	20·19	19·25	18·01	13·25	13·71	16·64	18·40	16·59	Total.
1556	1577	1670	2175	1459	1254	1713	1600	1663	Fresh produce.
1312	1331	1426	1838	1248	1070	1432	1345	1390	Dry matter.
5·4	6·0	6·4	9·4	7·2	6·7	6·3	4·4	7·0	Nitrogen.
0·90	1·05	0·53	0·90	1·37	0·23	0·67	0·32	0·73	Ferric oxide.
3·54	1·86	4·82	5·95	4·26	3·14	3·70	4·20	3·45	Lime.
1·30	2·24	1·72	1·56	1·08	1·06	1·28	1·42	1·88	Magnesia.
9·13	9·67	13·67	12·84	11·99	15·15	10·78	12·47	12·93	Potash.
0·46	1·35	0·49	0·62	0·35	0·26	0·35	0·24	0·49	Soda.
3·08	2·25	2·38	3·58	3·62	2·69	3·02	3·03	3·36	Phosphoric anhydride.
2·44	1·75	3·49	3·35	2·48	2·97	2·59	2·74	2·78	Sulphuric anhydride.
1·13	1·39	2·06	1·37	1·19	2·34	1·19	1·96	1·68	Chlorine.
55·25	42·85	50·35	68·04	77·87	45·95	75·30	69·83	62·55	Silica.
77·23	64·41	79·51	98·21	104·21	73·79	98·88	96·21	89·85	Total.
0·26	0·31	0·46	0·31	0·26	0·53	0·28	0·44	0·38	Deduct O = Cl.
76·97	64·10	79·05	97·90	103·95	73·26	98·60	95·77	89·47	Total.
2450	2813	2811	3226	2197	1990	2709	2727	2653	Fresh produce.
2045	2380	2379	2704	1861	1696	2252	2291	2215	Dry matter.
19·4	26·0	24·1	26·4	19·0	19·5	20·7	20·0	22·7	Nitrogen.
1·03	1·27	0·73	1·07	1·58	0·37	0·89	0·41	0·89	Ferric oxide.
3·92	2·54	5·35	6·44	4·62	3·51	4·12	4·69	3·92	Lime.
2·91	4·42	3·74	3·54	2·29	2·37	2·98	3·43	3·60	Magnesia.
13·70	16·13	19·97	18·59	16·44	19·87	16·16	18·42	18·39	Potash.
0·56	1·44	0·58	0·69	0·45	0·33	0·55	0·38	0·59	Soda.
10·93	12·34	12·17	12·69	9·91	9·20	11·27	12·52	11·64	Phosphoric anhydride.
2·60	2·01	3·62	3·58	2·77	3·20	2·86	2·86	2·99	Sulphuric anhydride.
1·13	1·40	2·06	1·39	1·22	2·36	1·20	1·96	1·69	Chlorine.
55·40	43·05	50·54	68·23	78·19	46·29	75·49	69·94	62·73	Silica.
92·18	84·60	98·76	116·22	117·47	87·50	115·52	114·61	106·44	Total.
0·26	0·31	0·46	0·31	0·27	0·53	0·28	0·44	0·38	Deduct O = Cl.
91·92	84·29	98·30	115·91	117·20	86·97	115·24	114·17	106·06	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table IX.—General Characters of the Produce, and Quantities of (pure), *per Acre*, in Grain, Straw, and Total Produce,

Plot 10a.—Ammonium-Salts alone, every year.

Harvests		1848	1849	1850	1851	1852	1853	1854	1855
Grain to 100 straw		56·3	75·1	55·7	64·0	47·3	31·3	61·5	51·2
Weight per bushel of grain, lbs.		58·1	62·3	60·2	61·9	55·9	48·6	60·5	57·1
Produce of grain, per acre, lbs.	Fresh produce	1334	2141	1721	1966	1320	642	2211	1285
	Dry matter	1083	1771	1451	1661	1106	517	1877	1082
	Nitrogen	26·2	34·5	30·9	35·7	27·4	12·6	43·2	26·0
Ash-constituents of grain, per acre, lbs.	Ferric oxide	0·22	0·23	0·21	0·25	0·13	0·12	0·25	0·15
	Lime	0·68	1·02	0·98	1·05	0·71	0·38	1·09	0·74
	Magnesia	2·29	3·04	2·89	3·20	2·57	0·95	3·28	2·14
	Potash	6·48	10·51	8·96	9·79	5·69	3·66	11·54	7·14
	Soda	0·17	0·13	0·08	0·20	0·10	0·08	0·17	0·07
	Phosphoric anhydride	10·86	13·56	13·30	14·88	10·72	4·56	14·87	9·80
	Sulphuric anhydride	0·17	0·80	0·42	0·44	0·13	0·25	0·72	0·33
	Chlorine	trace	0·01	0·01	0·01	trace	0·02	0·15	0·06
	Silica	0·30	0·25	0·16	0·19	0·21	0·19	0·23	0·20
	Total	21·17	29·55	27·01	30·01	20·26	10·21	32·30	20·63
	Deduct O = Cl	—	—	—	—	—	—	0·03	0·01
	Total	21·17	29·55	27·01	30·01	20·26	10·21	32·27	20·62
Produce of straw per acre, lbs.	Fresh produce	2367	2851	3089	3070	2787	2049	3597	2512
	Dry matter	1960	2392	2647	2606	2322	1658	3032	2087
	Nitrogen	16·1	20·3	20·6	19·3	20·7	21·4	17·0	12·9
Ash-constituents of straw, per acre, lbs.	Ferric oxide	0·60	1·08	0·61	0·74	0·98	1·16	0·52	0·34
	Lime	5·54	9·76	8·68	8·41	7·27	4·76	7·84	5·46
	Magnesia	1·52	3·02	3·06	3·33	2·09	1·29	2·39	1·48
	Potash	14·50	20·63	24·44	24·07	13·68	16·40	32·22	25·80
	Soda	0·79	2·56	2·41	2·09	1·71	0·85	0·71	1·01
	Phosphoric anhydride	3·44	3·78	4·87	5·12	3·26	4·21	2·95	2·45
	Sulphuric anhydride	3·28	4·95	5·83	4·63	3·31	3·15	6·56	5·25
	Chlorine	2·03	4·60	5·25	5·82	2·01	2·44	6·96	5·30
	Silica	75·28	90·00	86·24	88·31	96·11	63·39	79·10	71·16
	Total	106·98	140·38	141·39	142·52	130·42	97·65	139·25	118·25
	Deduct O = Cl	0·46	1·04	1·17	1·32	0·46	0·55	1·57	1·19
	Total	106·52	139·34	140·22	141·20	129·96	97·10	137·68	117·06
Total produce (grain and straw), per acre, lbs.	Fresh produce	3701	4992	4810	5036	4107	2691	5808	3797
	Dry matter	3043	4163	4098	4267	3428	2175	4909	3169
	Nitrogen	42·3	54·8	51·5	55·0	48·1	34·0	60·2	38·9
Ash-constituents of total produce (grain and straw), per acre, lbs.	Ferric oxide	0·82	1·31	0·82	0·99	1·11	1·28	0·77	0·49
	Lime	6·22	10·78	9·66	9·46	7·98	5·14	8·93	6·20
	Magnesia	3·81	6·06	5·95	6·53	4·66	2·24	5·67	3·62
	Potash	20·98	31·14	33·40	33·86	19·37	20·06	43·76	32·94
	Soda	0·96	2·69	2·49	2·29	1·81	0·93	0·88	1·08
	Phosphoric anhydride	14·30	17·34	18·17	20·00	13·98	8·77	17·82	12·25
	Sulphuric anhydride	3·45	5·75	6·25	5·07	3·44	3·40	7·28	5·58
	Chlorine	2·03	4·61	5·26	5·83	2·01	2·46	7·11	5·36
	Silica	75·58	90·25	86·40	88·50	96·32	63·58	79·33	71·36
	Total	128·15	169·93	168·40	172·53	150·68	107·86	171·55	138·88
	Deduct O = Cl	0·46	1·04	1·17	1·32	0·46	0·55	1·60	1·20
	Total	127·69	168·89	167·23	171·21	150·22	107·31	169·95	137·68

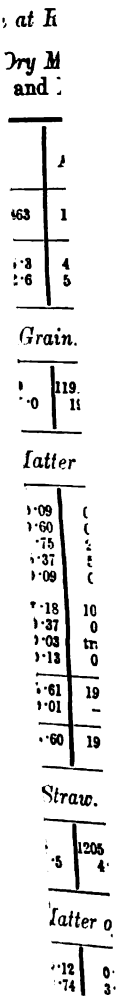
grown at Rothamsted, year after year on the same Land.

Fresh Produce, Dry Matter, Nitrogen, Ash-Constituents, and Total Ash in sixteen consecutive Seasons, 1848–1863.

Plot 10a.—Ammonium-Salts alone, every year.

1856	1857	1858	1859	1860	1861	1862	1863	Average.	Harvests.
53·4	75·9	67·6	44·2	40·9	44·2	56·2	74·3	57·2	Grain to 100 straw.
55·6	58·0	59·6	51·5	49·5	55·0	56·5	62·6	57·1	Wt. per bushel of grain, lbs.
1505	1816	1439	1207	905	854	1457	2587	1524	Fresh produce.
1264	1542	1208	994	770	725	1217	2194	1279	Dry matter.
28·2	32·1	26·9	22·9	17·2	15·1	23·0	37·3	27·5	Nitrogen.
0·14	0·32	0·14	0·18	0·30	0·10	0·24	0·21	0·20	Ferric oxide.
0·84	1·11	0·93	0·67	0·56	0·51	0·80	1·32	0·84	Lime.
2·67	2·94	2·41	2·08	1·49	1·45	2·41	3·83	2·48	Magnesia.
7·44	7·96	7·68	6·05	5·68	5·16	7·66	11·78	7·70	Potash.
0·09	0·10	0·09	0·14	0·10	0·07	0·21	0·19	0·12	Soda.
11·69	11·84	10·69	8·73	7·07	6·48	9·94	15·76	10·92	Phosphoric anhydride.
0·23	0·53	0·63	0·44	0·58	0·38	0·65	0·81	0·47	Sulphuric anhydride.
none	0·03	0·13	0·01	0·14	0·17	0·15	0·07	0·06	Chlorine.
0·26	0·38	0·23	0·22	0·43	0·25	0·40	0·29	0·26	Silica.
23·36	25·21	22·93	18·52	16·35	14·57	22·46	34·26	23·05	Total.
—	0·01	0·03	—	0·03	0·04	0·03	0·02	0·01	Deduct O = Cl.
23·36	25·20	22·90	18·52	16·32	14·53	22·43	34·24	23·04	Total.
2818	2392	2130	2730	2213	1930	2593	3481	2663	Fresh produce.
2347	2033	1819	2327	1876	1635	2162	2930	2240	Dry matter.
11·7	11·4	11·5	14·9	10·3	11·6	12·5	10·3	15·1	Nitrogen.
0·76	0·85	0·47	0·90	1·65	0·19	0·53	0·35	0·73	Ferric oxide.
5·98	6·30	7·25	8·35	5·03	5·49	6·81	10·95	7·12	Lime.
1·30	1·52	2·05	2·02	1·71	1·86	2·42	2·75	2·11	Magnesia.
15·00	14·17	14·55	13·25	23·31	21·65	16·09	22·57	19·52	Potash.
1·84	0·65	0·97	1·88	0·19	1·77	1·20	0·83	1·34	Soda.
3·58	2·42	2·64	3·54	6·50	2·83	3·95	2·73	3·65	Phosphoric anhydride.
4·28	3·43	6·55	4·53	4·49	4·76	4·06	6·13	4·70	Sulphuric anhydride.
1·71	2·21	2·38	1·77	2·34	3·74	1·99	5·62	3·51	Chlorine.
73·39	49·89	47·60	63·88	106·95	56·12	81·27	107·67	77·27	Silica.
107·84	81·44	84·46	100·12	152·17	98·41	118·32	159·60	119·95	Total.
0·39	0·50	0·54	0·40	0·53	0·84	0·45	1·27	0·79	Deduct O = Cl.
107·45	80·94	83·92	99·72	151·64	97·57	117·87	158·33	119·16	Total.
4323	4208	3569	3937	3118	2784	4050	6068	4187	Fresh produce.
3511	3575	3027	3321	2646	2360	3379	5124	3519	Dry matter.
39·9	43·5	38·4	37·8	27·5	26·7	35·5	47·6	42·6	Nitrogen.
0·90	1·17	0·61	1·08	1·95	0·29	0·77	0·56	0·93	Ferric oxide.
6·62	7·41	8·18	9·02	5·59	6·00	7·61	12·27	7·96	Lime.
3·97	4·46	4·46	4·10	3·20	3·31	4·83	6·58	4·59	Magnesia.
22·44	22·18	22·23	19·30	28·99	26·81	23·75	34·35	27·22	Potash.
1·93	0·75	1·06	2·02	0·29	1·84	1·41	1·02	1·46	Soda.
15·27	14·26	13·38	12·27	13·57	9·31	13·89	18·49	14·57	Phosphoric anhydride.
4·51	3·96	7·18	4·97	5·07	5·14	4·71	6·94	5·17	Sulphuric anhydride.
1·71	2·24	2·51	1·78	2·48	3·91	2·14	5·60	3·57	Chlorine.
73·65	50·27	47·83	64·10	107·38	56·37	81·67	107·96	77·53	Silica.
131·20	106·65	107·39	118·64	168·52	112·98	140·78	193·86	143·00	Total.
0·39	0·51	0·57	0·40	0·56	0·88	0·48	1·29	0·80	Deduct O = Cl.
130·81	106·14	106·82	118·24	167·96	112·10	140·30	192·57	142·20	Total.

[redacted]



at R

ry M
and 1

	A
63	1.
·3	4
·6	5

Grain.

·0	1191
	19

Matter

·09	0
·60	0
·75	2
·37	5
·09	0
·18	10
·37	0
·03	tr
·13	0
·61	19
·01	
·60	19

Straw.

·5	1205
	4

Matter o

·12	0
·74	3

ou

ent

, 1

ne.

It

re,

587
194
37

A

0
1
3
11
0

15
0
0
0

34
0

34

re,

481
930
10

£

0
10
?

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table XIII.—General Characters of the Produce, and *Percentage* mixed Samples of the Grain, and proportionally mixed Samples of the differently manured Plots in each Case.

Plots and manures.	2. Farmyard manure.		3. Unmanured.		5*b*. Mixed min. man.		7*b*. Mixed min. and amm.		10*a*. Amm. salts alone.	
	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.
Grain to 100 straw...	56·5	62·7	56·8	71·0	59·2	67·9	52·7	59·9	52·4	66·3
Weight per bushel of grain, lbs.	58·8	61·3	55·8	54·9	57·2	60·5	57·8	60·7	55·1	59·1
Composition of the Grain, per cent.										
Dry matter	84·00	84·17	83·63	84·23	83·60	84·27	84·19	84·45	84·07	85·06
Nitrogen in dry matter	2·05	1·84	1·98	1·70	1·95	1·71	2·09	1·85	2·07	1·90
Ash (pure) in dry matter	2·06	1·92	2·08	2·00	2·10	2·03	1·99	1·89	1·88	1·72
Composition of the Grain-Ash (pure), per cent.										
Ferric oxide	0·53	0·45	0·72	0·57	0·63	0·52	0·71	0·56	0·73	0·61
Lime.....	2·49	2·59	3·13	3·22	2·66	2·82	2·79	2·94	3·90	4·35
Magnesia	10·93	10·97	10·44	10·52	10·54	10·65	10·62	10·71	10·42	10·89
Potash	31·69	32·20	33·52	33·17	32·34	32·76	32·87	33·42	34·01	34·12
Soda	0·22	0·16	0·23	0·13	0·26	0·10	0·20	0·12	0·18	0·22
Phosphoric anhydride.	52·81	52·16	49·83	50·30	51·74	50·85	50·95	50·14	46·29	45·79
Sulphuric anhydride.	0·55	0·89	1·40	1·44	0·82	1·69	1·16	1·46	2·84	3·03
Chlorine	0·01	0·02	0·03	0·07	0·01	0·02	0·01	0·01	0·59	0·42
Silica.....	0·77	0·56	0·71	0·60	1·00	0·59	0·69	0·64	1·17	0·66
Total.....	100·00	100·00	100·01	100·02	100·00	100·00	100·00	100·00	100·13	100·09
Deduct O = Cl	—	—	0·01	0·02	—	—	—	—	0·13	0·09
Total.....	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
Composition of the Straw, per cent.										
Dry matter	84·03	84·08	83·96	84·47	84·09	84·26	83·75	83·92	84·01	84·58
Nitrogen in dry matter	0·50	0·43	0·54	0·47	0·59	0·44	0·56	0·43	0·58	0·55
Ash (pure) in dry matter	6·44	6·55	6·08	6·68	6·45	6·91	5·43	5·11	5·27	5·46
Composition of the Straw-Ash (pure), per cent.										
Ferric oxide	0·45	0·29	0·73	0·65	0·74	0·66	0·56	0·34	0·64	0·42
Lime.....	3·96	4·25	5·03	5·12	4·00	4·20	5·15	6·00	5·93	7·41
Magnesia	1·27	1·45	1·49	1·56	1·26	1·44	1·46	1·83	1·63	2·02
Potash	19·87	19·60	15·88	14·83	18·76	17·86	23·65	24·64	18·15	14·23
Soda	0·11	0·15	0·32	0·21	0·14	0·21	0·23	0·16	0·85	0·84
Phosphoric anhydride.	3·34	3·43	3·09	3·11	3·93	4·12	2·90	2·98	3·05	2·79
Sulphuric anhydride.	3·40	2·93	4·11	3·57	4·32	4·70	4·48	4·28	5·05	4·86
Chlorine	3·30	3·46	2·01	2·25	2·43	2·46	4·56	5·64	2·87	2·49
Silica.....	65·05	65·22	67·80	69·21	64·97	64·90	58·04	55·40	62·48	65·50
Total.....	100·75	100·78	100·46	100·51	100·55	100·55	101·03	101·27	100·65	100·56
Deduct O = Cl	0·75	0·78	0·46	0·51	0·55	0·55	1·03	1·27	0·65	0·56
Total.....	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00

Straw, grown at Rothamsted, year after year on the same Land.

Composition of the Ash (excluding Sand and Charcoal), of proportionally Straw, of ten Years, 1852–1861, and of ten Years, 1862–1871, from ten

10*b*. Amm. salts alone.		11*b*. Amm. and superph.		12*b*. Amm., superph., and soda.		13*b*. Amm., superph., and pot.		14*b*. Amm., superph., and magn.		Plots and manures.
10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
53·2	66·5	55·5	64·5	54·5	63·3	53·9	59·9	53·4	64·5	Grain to 100 straw.
56·3	59·6	55·9	58·9	58·0	60·4	58·3	61·2	58·0	60·6	Weight per bushel of grain, lbs.
Composition of the Grain, per cent.										
83·87	85·11	83·96	85·00	83·86	85·07	84·10	84·88	83·93	84·91	Dry matter.
2·07	1·82	2·07	1·84	2·03	1·80	1·99	1·74	2·05	1·75	Nitrogen in dry matter.
1·88	1·75	1·96	1·79	1·97	1·84	1·95	1·86	1·97	1·87	Ash (pure) in dry matter.
Composition of the Grain-Ash (pure), per cent.										
0·67	0·56	0·61	0·46	0·56	0·52	0·66	0·62	0·72	0·53	Ferric oxide.
3·41	4·17	3·87	4·31	2·97	3·57	2·88	2·96	2·87	3·41	Lime.
10·58	10·87	10·52	10·59	10·57	10·61	10·50	10·54	10·70	10·95	Magnesia.
33·92	34·12	31·73	32·10	32·77	33·33	32·93	33·52	32·57	33·06	Potash.
0·23	0·17	0·11	0·26	0·19	0·20	0·14	0·14	0·18	0·10	Soda.
48·59	47·04	50·76	49·67	50·96	50·01	51·46	50·18	51·55	50·30	Phosphoric anhydride.
1·69	2·26	1·56	1·91	1·37	1·18	0·71	1·43	0·73	1·00	Sulphuric anhydride.
0·16	0·27	0·01	0·18	0·01	0·01	0·01	0·01	0·01	0·01	Chlorine.
0·78	0·60	0·83	0·56	0·60	0·57	0·71	0·60	0·67	0·64	Silica.
100·03	100·06	100·00	100·04	100·00	100·00	100·00	100·00	100·00	100·00	Total.
0·03	0·06	—	0·04	—	—	—	—	—	—	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.
Composition of the Straw, per cent.										
83·82	84·53	84·03	83·88	83·61	84·27	83·37	84·12	83·97	84·03	Dry matter.
0·56	0·56	0·57	0·58	0·49	0·42	0·49	0·48	0·53	0·46	Nitrogen in dry matter.
5·11	5·08	5·41	5·24	5·25	5·32	5·35	5·32	5·31	5·15	Ash (pure) in dry matter.
Composition of the Straw-Ash (pure), per cent.										
0·84	0·43	0·58	0·46	0·52	0·39	0·50	0·32	0·48	0·41	Ferric oxide.
5·92	8·02	5·94	8·56	5·29	7·27	5·22	5·91	5·27	6·90	Lime.
1·65	2·24	1·63	2·26	1·46	1·93	1·38	1·66	1·55	2·18	Magnesia.
19·39	14·81	14·77	14·08	20·05	17·20	24·10	25·00	21·95	18·54	Potash.
0·58	1·09	1·06	1·96	0·53	1·11	0·21	0·06	0·32	0·73	Soda.
2·97	2·55	3·39	3·63	3·24	3·14	2·98	2·97	2·85	3·24	Phosphoric anhydride.
4·58	4·40	4·35	4·63	4·46	4·07	4·55	3·89	4·60	4·16	Sulphuric anhydride.
3·18	3·30	2·45	3·75	3·58	3·73	4·75	5·69	4·29	4·05	Chlorine.
61·61	63·90	66·39	61·51	61·67	62·00	57·39	55·79	59·66	60·70	Silica.
100·72	100·74	100·56	100·84	100·80	100·84	101·08	101·29	100·97	100·91	Total.
0·72	0·74	0·56	0·84	0·80	0·84	1·08	1·29	0·97	0·91	Deduct O = Cl.
100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table XIV.—General Characters of the Produce, and Amounts of 100° C.), of proportionally mixed Samples of the Grain, and proportionally 1862–1871; from ten differently manured Plots in each Case.

Plots and manures.	2. Farmyard manure.		3. Unmanured.		5b. Mixed min. man.		7b. Mixed min. and amm.		10a. Amm. salts alone.	
	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.
Gr. to 100 stw.	56·5	62·7	56·8	71·0	59·2	67·9	52·7	59·9	52·4	66·3
Wt. per bush. grain, lbs.	58·8	61·3	55·8	59·4	57·2	60·5	57·8	60·7	55·1	59·1

Per 1000 *Dry Matter of Grain.*

Fresh produce Nitrogen	1190 20·5	1188 18·4	1195 19·8	1187 17·0	1197 19·5	1186 17·1	1188 20·9	1184 18·5	1190 20·7	1176 19·0
Ferric oxide	0·11	0·09	0·15	0·11	0·13	0·11	0·14	0·11	0·14	0·11
Lime	0·51	0·50	0·65	0·65	0·56	0·57	0·55	0·56	0·73	0·75
Magnesia	2·25	2·10	2·17	2·11	2·21	2·16	2·11	2·03	1·96	1·88
Potash	6·52	6·18	6·98	6·65	6·79	6·66	6·53	6·33	6·39	5·87
Soda	0·05	0·03	0·05	0·03	0·06	0·02	0·04	0·02	0·03	0·04
Phosp. anhyd.	10·87	10·01	10·37	10·07	10·86	10·35	10·12	9·49	8·70	7·89
Sulph. anhyd.	0·11	0·17	0·29	0·29	0·17	0·35	0·23	0·28	0·53	0·52
Chlorine	trace	trace	trace	0·01	trace	0·01	trace	trace	0·11	0·07
Silica	0·16	0·11	0·15	0·12	0·21	0·12	0·14	0·12	0·22	0·11
Total	20·58	19·19	20·81	20·04	20·99	20·35	19·86	18·94	18·81	17·24
Deduct O=Cl	—	—	—	—	—	—	—	—	0·02	0·02
Total	20·58	19·19	20·81	20·04	20·99	20·35	19·86	18·94	18·79	17·22

Per 1000 *Dry Matter of Straw.*

Fresh produce Nitrogen	1190 5·0	1189 4·3	1191 5·4	1184 4·7	1189 5·9	1187 4·4	1194 5·6	1192 4·3	1190 5·8	1182 5·5
Ferric oxide	0·29	0·19	0·44	0·43	0·48	0·45	0·30	0·17	0·34	0·23
Lime	2·55	2·78	3·06	3·42	2·58	2·90	2·80	3·06	3·13	4·04
Magnesia	0·81	0·95	0·91	1·04	0·81	0·99	0·79	0·94	0·86	1·10
Potash	12·80	12·83	9·65	9·91	12·09	12·34	12·84	12·58	9·57	7·76
Soda	0·07	0·10	0·19	0·14	0·09	0·14	0·12	0·08	0·45	0·46
Phosp. anhyd.	2·15	2·25	1·88	2·08	2·53	2·84	1·57	1·52	1·61	1·52
Sulph. anhyd.	2·19	1·92	2·49	2·39	2·78	3·25	2·43	2·19	2·66	2·66
Chlorine	2·13	2·27	1·22	1·50	1·57	1·70	2·48	2·88	1·51	1·36
Silica	41·91	42·71	41·19	46·25	41·88	44·83	31·50	28·29	32·94	35·75
Total	64·90	66·00	61·03	67·16	64·81	69·44	54·83	51·71	53·07	54·88
Deduct O=Cl	0·48	0·51	0·28	0·34	0·36	0·38	0·56	0·65	0·34	0·30
Total	64·42	65·49	60·75	66·82	64·45	69·06	54·27	51·06	52·73	54·58

Per 1000 *Dry Matter of Total Produce (Grain and Straw).*

Fresh produce Nitrogen	1190 10·6	1189 9·7	1193 10·6	1185 9·8	1192 10·9	1187 9·5	1192 10·9	1189 9·6	1190 10·9	1180 10·9
Ferric oxide	0·22	0·15	0·34	0·30	0·35	0·31	0·25	0·15	0·27	0·18
Lime	1·82	1·90	2·19	2·27	1·83	1·96	2·02	2·12	2·30	2·73
Magnesia	1·33	1·40	1·37	1·48	1·33	1·47	1·25	1·35	1·24	1·41
Potash	10·54	10·27	8·68	8·55	10·12	10·04	10·65	10·23	8·48	7·01
Soda	0·06	0·07	0·14	0·09	0·07	0·09	0·09	0·06	0·31	0·29
Phosp. anhyd.	5·30	5·24	4·94	5·40	5·62	5·88	4·53	4·52	4·04	4·07
Sulph. anhyd.	1·44	1·25	1·70	1·52	1·82	2·07	1·67	1·47	1·93	1·80
Chlorine	1·36	1·39	0·78	0·88	0·99	1·01	1·62	1·80	1·03	0·84
Silica	26·83	26·28	26·35	27·13	26·44	26·74	20·64	17·69	21·69	21·49
Total	48·90	47·95	46·49	47·62	48·57	49·57	42·72	39·39	41·29	39·82
Deduct O=Cl	0·31	0·31	0·18	0·20	0·22	0·22	0·37	0·41	0·23	0·19
Total	48·59	47·64	46·31	47·42	48·35	49·35	42·35	38·98	41·06	39·63

Straw, grown at Rothamsted, year after year on the same Land.

Nitrogen, Ash-Constituents, and Total Ash (pure), *per* 1000 *Dry Matter* (at mixed Samples of the Straw, of ten Years, 1852–1861, and of ten Years

10*b*. Amm. salts alone.		11*b*. Amm. and superph.		12*b*. Amm., superph., and soda.		13*b*. Amm., superph., and pot.		14*b*. Amm., superph., and magn.		Plots and manures.
10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
53·2	66·5	55·5	64·5	54·5	63·3	53·9	59·9	53·4	64·5	Gr. to 100 stw.
56·3	59·6	55·9	58·9	58·0	60·4	58·3	61·2	58·0	60·6	Wt. per bush. grain, lbs.

Per 1000 *Dry Matter of Grain.*

1192 20·7	1172 18·2	1191 20·7	1177 18·4	1192 20·3	1176 18·0	1189 19·9	1178 17·4	1192 20·5	1177 17·5	Fresh produce. Nitrogen.
0·13	0·10	0·12	0·08	0·11	0·09	0·13	0·11	0·14	0·10	Ferric oxide.
0·64	0·73	0·76	0·77	0·58	0·66	0·56	0·55	0·56	0·64	Lime.
1·99	1·90	2·06	1·90	2·08	1·95	2·05	1·96	2·11	2·04	Magnesia.
6·39	5·98	6·22	5·76	6·46	6·14	6·43	6·22	6·41	6·16	Potash.
0·04	0·03	0·02	0·05	0·04	0·04	0·03	0·03	0·04	0·02	Soda.
9·16	8·24	9·95	8·92	10·05	9·21	10·05	9·31	10·15	9·38	Phosp. anhyd.
0·32	0·39	0·31	0·34	0·27	0·22	0·14	0·27	0·15	0·19	Sulph. anhyd.
0·03	0·05	trace	0·03	trace	trace	trace	trace	trace	trace	Chlorine.
0·15	0·11	0·16	0·10	0·12	0·10	0·14	0·11	0·13	0·12	Silica.
18·85	17·53	19·60	17·95	19·71	18·42	19·53	18·56	19·69	18·65	Total.
0·01	0·01	—	0·01	—	—	—	—	—	—	Deduct O=Cl.
18·84	17·52	19·60	17·94	19·71	18·42	19·53	18·56	19·69	18·65	Total.

Per 1000 *Dry Matter of Straw.*

1193 5·6	1183 5·6	1190 5·7	1192 5·8	1196 4·9	1187 4·2	1200 4·9	1189 4·8	1191 5·3	1190 4·6	Fresh produce. Nitrogen.
0·43	0·22	0·31	0·24	0·27	0·21	0·26	0·17	0·26	0·21	Ferric oxide.
3·02	4·08	3·22	4·48	2·78	3·86	2·80	3·15	2·80	3·56	Lime.
0·84	1·14	0·88	1·18	0·77	1·03	0·74	0·88	0·82	1·13	Magnesia.
9·30	7·53	8·00	7·37	10·54	9·14	12·90	13·29	11·65	9·55	Potash.
0·30	0·56	0·57	1·03	0·28	0·59	0·11	0·03	0·17	0·37	Soda.
1·52	1·29	1·84	1·90	1·70	1·66	1·59	1·58	1·51	1·67	Phosp. anhyd.
2·34	2·23	2·35	2·42	2·34	2·17	2·43	2·06	2·45	2·14	Sulph. anhyd.
1·62	1·67	1·33	1·97	1·88	1·99	2·55	3·03	2·28	2·09	Chlorine.
31·47	32·47	35·94	32·20	32·39	32·96	30·70	29·66	31·69	31·28	Silica.
51·44	51·19	54·44	52·79	52·95	53·61	54·08	53·85	53·63	52·00	Total.
0·36	0·37	0·30	0·44	0·42	0·45	0·58	0·68	0·51	0·47	Deduct O=Cl.
51·08	50·82	54·14	52·35	52·53	53·16	53·50	53·17	53·12	51·53	Total.

Per 1000 *Dry Matter of Total Produce* (*Grain and Straw*).

1193 10·6	1179 10·7	1191 11·1	1186 10·8	1195 10·3	1183 9·6	1196 10·2	1185 9·5	1191 10·6	1185 9·7	Fresh produce. Nitrogen.
0·22	0·17	0·25	0·18	0·22	0·16	0·22	0·15	0·22	0·17	Ferric oxide.
2·20	2·73	2·34	3·02	2·00	2·61	2·01	2·17	2·02	2·41	Lime.
1·24	1·45	1·30	1·47	1·23	1·39	1·20	1·29	1·27	1·49	Magnesia.
8·68	6·90	7·36	6·73	9·10	7·97	10·62	10·63	9·83	8·22	Potash.
0·21	0·35	0·38	0·64	0·19	0·37	0·08	0·03	0·12	0·23	Soda.
4·17	4·08	4·73	4·67	4·65	4·61	4·57	4·49	4·52	4·71	Phosp. anhyd.
1·64	1·50	1·62	1·60	1·61	1·41	1·62	1·38	1·65	1·37	Sulph. anhyd.
1·07	1·02	0·86	1·20	1·22	1·21	1·65	1·89	1·49	1·26	Chlorine.
20·59	19·47	23·17	19·51	20·99	20·15	19·94	18·53	20·71	18·98	Silica.
40·12	37·67	42·01	39·02	41·21	39·88	41·91	40·56	41·83	38·84	Total.
0·24	0·23	0·19	0·27	0·28	0·27	0·37	0·43	0·34	0·28	Deduct O=Cl.
39·88	37·44	41·82	38·75	40·93	39·61	41·54	40·13	41·49	38·56	Total.

Composition of the Ash of Wheat-Grain, and of Wheat-

Appendix-Table XV.—General Characters of the Produce, and Quantities of Fresh Produce, mixed Samples of the Grain, and proportionally mixed Samples of the Straw, of ten Years,

Plots and manures.	2. Farmyard manure.		3. Unmanured.		5b. Mixed min. man.		7b. Mixed min. and amm.		10a. Amm. salts alone.	
	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.
Gr. to 100 stw.	56·5	62·7	56·8	71·0	59·2	67·9	52·7	59·9	52·4	66·3
Wt. per bush. grain, lbs.	58·8	61·3	55·8	59·4	57·2	60·5	57·8	60·7	55·1	59·1

Produce of Grain, per Acre, lbs.

Fresh produce	2145	2385	944	881	1163	1007	2163	2309	1318	1553
Dry matter ...	1802	2008	790	742	972	849	1821	1950	1108	1321
Nitrogen	36·9	36·9	15·6	12·6	19·0	14·5	38·1	36·1	22·9	25·1
Ferric oxide ...	0·20	0·18	0·12	0·09	0·13	0·09	0·26	0·21	0·16	0·14
Lime	0·93	1·00	0·51	0·48	0·54	0·49	1·01	1·09	0·81	0·99
Magnesia	4·05	4·23	1·72	1·56	2·15	1·84	3·84	3·96	2·17	2·47
Potash	11·76	12·41	5·51	4·93	6·60	5·66	11·89	12·34	7·08	7·76
Soda	0·08	0·06	0·04	0·02	0·05	0·02	0·08	0·04	0·04	0·05
Phosp. anhyd.	19·59	20·10	8·19	7·47	10·55	8·78	18·42	18·52	9·64	10·42
Sulph. anhyd.	0·20	0·34	0·23	0·22	0·17	0·30	0·42	0·54	0·59	0·69
Chlorine.....	trace	0·01	trace	0·01	trace	trace	trace	trace	0·12	0·10
Silica	0·29	0·21	0·12	0·09	0·21	0·10	0·25	0·24	0·24	0·15
Total	37·10	38·54	16·44	14·87	20·40	17·28	36·17	36·94	20·85	22·77
Deduct O=Cl	—	—	—	—	—	—	—	—	0·03	0·02
Total	37·10	38·54	16·44	14·87	20·40	17·28	36·17	36·94	20·82	22·75

Produce of Straw, per Acre, lbs.

Fresh produce	3795	3803	1663	1241	1963	1483	4104	3857	2516	2341
Dry matter ...	3189	3198	1396	1048	1651	1249	3437	3237	2114	1980
Nitrogen	15·9	13·8	7·5	4·9	9·7	5·5	19·2	13·9	12·3	10·9
Ferric oxide ...	0·91	0·60	0·62	0·45	0·79	0·57	1·04	0·56	0·71	0·45
Lime	8·14	8·90	4·27	3·58	4·26	3·62	9·62	9·92	6·62	8·00
Magnesia	2·59	3·03	1·27	1·09	1·34	1·24	2·71	3·03	1·81	2·19
Potash	40·82	41·05	13·46	10·38	19·96	15·41	44·12	40·72	20·23	15·37
Soda	0·23	0·32	0·27	0·14	0·15	0·18	0·42	0·27	0·95	0·91
Phosp. anhyd.	6·86	7·19	2·62	2·19	4·19	3·55	5·41	4·91	3·39	3·01
Sulph. anhyd.	6·99	6·14	3·48	2·50	4·59	4·05	8·35	7·07	5·62	5·26
Chlorine	6·78	7·25	1·71	1·57	2·59	2·12	8·52	9·33	3·20	2·69
Silica	133·64	136·60	57·50	48·47	69·14	55·99	108·26	91·56	69·65	70·79
Total	206·96	211·08	85·20	70·37	107·01	86·73	188·45	167·37	112·18	108·67
Deduct O=Cl	1·53	1·63	0·39	0·35	0·59	0·48	1·92	2·09	0·72	0·61
Total	205·43	209·45	84·81	70·02	106·42	86·25	186·53	165·28	111·46	108·06

Total Produce (Grain and Straw), per Acre, lbs.

Fresh produce	5940	6188	2607	2122	3126	2490	6267	6166	3834	3894
Dry matter ...	4991	5206	2186	1790	2623	2098	5258	5187	3222	3301
Nitrogen	52·8	50·7	23·1	17·5	28·7	20·0	57·3	50·0	35·2	36·0
Ferric oxide ...	1·11	0·78	0·74	0·54	0·92	0·66	1·30	0·77	0·87	0·59
Lime	9·07	9·90	4·78	4·06	4·80	4·11	10·63	11·01	7·43	8·99
Magnesia	6·64	7·26	2·99	2·65	3·49	3·08	6·55	6·99	3·98	4·66
Potash	52·58	53·46	18·97	15·31	26·56	21·07	56·01	53·06	27·31	23·13
Soda	0·31	0·38	0·31	0·16	0·20	0·20	0·50	0·31	0·99	0·96
Phosp. anhyd.	26·45	27·29	10·81	9·66	14·74	12·33	23·83	23·43	13·03	13·43
Sulph. anhyd.	7·19	6·48	3·71	2·72	4·76	4·35	8·77	7·61	6·21	5·95
Chlorine.....	6·78	7·26	1·71	1·58	2·59	2·12	8·52	9·33	3·32	2·79
Silica	133·93	136·81	57·62	48·56	69·35	56·09	108·51	91·80	69·89	70·94
Total	244·06	249·62	101·64	85·24	127·41	104·01	224·62	204·31	133·03	131·44
Deduct O=Cl	1·53	1·63	0·39	0·35	0·59	0·48	1·92	2·09	0·75	0·63
Total	242·53	247·99	101·25	84·89	126·82	103·53	222·70	202·22	132·28	130·81

Straw, grown at Rothamsted, year after year on the same Land.

Dry Matter, Nitrogen, Ash-Constituents, and Total Ash (pure), *per Acre*, of proportionally 1852–1861, and ten Years, 1862–1871, from ten differently manured Plots in each Case.

10*b*. Amm. salts alone.		11*b*. Amm. and superph.		12*b*. Amm. superph. and soda.		13*b*. Amm. superph. and pot.		14*b*. Amm. superph. and magn.		Plots and manures.
10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	10 years, 1852–'61.	10 years, 1862–'71.	
53·2	66·5	55·5	64·5	54·5	63·3	53·9	59·9	53·4	64·5	Gr. to 100 stw.
56·3	59·6	55·9	58·9	58·0	60·4	58·3	61·2	58·0	60·6	Wt. per bush. grain, lbs.

Produce of Grain, per Acre, lbs.

1586	1707	1782	1799	2101	2173	2098	2305	2101	2210	Fresh produce.
1330	1456	1496	1529	1762	1848	1764	1956	1763	1877	Dry matter.
27·5	26·5	31·0	28·1	35·8	33·3	35·1	34·0	36·1	32·8	Nitrogen.
0·17	0·15	0·18	0·13	0·19	0·18	0·23	0·22	0·25	0·19	Ferric oxide.
0·85	1·06	1·13	1·18	1·03	1·22	0·99	1·07	1·00	1·20	Lime.
2·65	2·77	3·09	2·90	3·67	3·61	3·62	3·83	3·71	3·83	Magnesia.
8·50	8·70	9·30	8·80	11·39	11·34	11·34	12·17	11·30	11·57	Potash.
0·06	0·04	0·03	0·07	0·07	0·07	0·04	0·05	0·06	0·04	Soda.
12·18	12·00	14·88	13·63	17·70	17·02	17·73	18·21	17·89	17·61	Phosp. anhyd.
0·42	0·58	0·46	0·53	0·47	0·40	0·25	0·52	0·26	0·35	Sulph. anhyd.
0·04	0·07	trace	0·05	trace	trace	trace	trace	trace	trace	Chlorine.
0·20	0·16	0·25	0·16	0·21	0·19	0·24	0·22	0·23	0·22	Silica.
25·07	25·53	29·32	27·45	34·73	34·03	34·44	36·29	34·70	35·01	Total.
0·01	0·02	—	0·01	—	—	—	—	—	—	Deduct O=Cl.
25·06	25·51	29·32	27·44	34·73	34·03	34·44	36·29	34·70	35·01	Total.

Produce of Straw, per Acre, lbs.

2984	2565	3209	2790	3857	3431	3893	3848	3937	3425	Fresh produce.
2501	2168	2696	2340	3224	2891	3245	3237	3306	2878	Dry matter.
14·0	12·1	15·4	13·6	15·8	12·1	15·9	15·5	17·5	13·2	Nitrogen.
1·07	0·47	0·84	0·56	0·88	0·60	0·86	0·55	0·85	0·60	Ferric oxide.
7·56	8·84	8·68	10·49	8·95	11·17	9·07	10·18	9·25	10·24	Lime.
2·11	2·47	2·36	2·78	2·48	2·97	2·41	2·86	2·73	3·24	Magnesia.
24·76	16·32	21·57	17·24	33·99	26·43	41·84	43·04	38·53	27·50	Potash.
0·74	1·21	1·54	2·40	0·90	1·70	0·36	0·11	0·56	1·07	Soda.
3·80	2·80	4·96	4·44	5·48	4·81	5·15	5·10	5·00	4·80	Phosp. anhyd.
5·85	4·84	6·34	5·67	7·54	6·26	7·89	6·68	8·08	6·17	Sulph. anhyd.
4·06	3·63	3·59	4·60	6·05	5·74	8·27	9·81	7·54	6·00	Chlorine.
78·70	70·39	96·90	75·35	104·44	95·29	99·63	96·00	104·76	90·04	Silica.
128·65	110·97	146·78	123·53	170·71	154·97	175·48	174·33	177·30	149·62	Total.
0·91	0·81	0·81	1·03	1·35	1·29	1·87	2·21	1·70	1·35	Deduct O=Cl.
127·74	110·16	145·97	122·50	169·36	153·68	173·61	172·12	175·60	148·32	Total.

Total Produce (Grain and Straw), per Acre, lbs.

4570	4272	4991	4589	5958	5604	5991	6153	6038	5635	Fresh produce.
3831	3624	4192	3869	4986	4739	5009	5193	5069	4755	Dry matter.
41·5	38·6	46·4	41·7	51·6	45·4	51·0	49·5	53·6	46·0	Nitrogen.
1·24	0·62	1·02	0·69	1·07	0·78	1·09	0·77	1·10	0·79	Ferric oxide.
8·41	9·90	9·81	11·67	9·98	12·39	10·06	11·25	10·25	11·44	Lime.
4·76	5·24	5·45	5·68	6·15	6·58	6·03	6·69	6·44	7·07	Magnesia.
33·26	25·02	30·87	26·04	45·38	37·77	53·18	55·21	49·83	39·07	Potash.
0·80	1·25	1·57	2·47	0·97	1·77	0·40	0·16	0·62	1·11	Soda.
15·98	14·80	19·84	18·07	23·18	21·83	22·88	23·31	22·89	22·41	Phosp. anhyd.
6·27	5·42	6·80	6·20	8·01	6·66	8·14	7·20	8·34	6·52	Sulph. anhyd.
4·10	3·70	3·59	4·65	6·05	5·74	8·27	9·81	7·54	6·00	Chlorine.
78·90	70·55	97·15	75·51	104·65	95·48	99·87	96·22	104·99	90·26	Silica.
153·72	136·50	176·10	150·98	205·44	189·00	209·92	210·62	212·00	184·67	Total.
0·92	0·83	0·81	1·04	1·35	1·29	1·87	2·21	1·70	1·35	Deduct O=Cl.
152·80	135·67	175·29	149·94	204·09	187·71	208·05	208·41	210·30	183·32	Total.

REPORT OF EXPERIMENTS

ON THE

GROWTH OF WHEAT

FOR THE SECOND PERIOD OF TWENTY YEARS
IN SUCCESSION ON THE SAME LAND.

BY

SIR J. BENNET LAWES, BART., LL.D., F.R.S.;

AND

J. H. GILBERT, LL.D., PH.D., F.R.S.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.
1885.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.
VOL. XX.—S. S. PART II.

CONTENTS.

PAGE

Introductory observations; comparison of the results of the two periods of 20 years. Knowledge gained by experience opens up new fields of investigation. The Agricultural Holdings Act 5

I.—Amount and Character of the Produce obtained in Different Seasons. General description of the weather in each season from 1864 to 1883; with tables showing the manures applied, and a summary of the results obtained .. 7

II.—Comparison of the produce of the Best Season, 1863, and the Worst Season, 1879, with the average of 32 years 37

III.—The produce obtained on the Permanently Unmanured Plot, over four periods of 10 years each, with the average of 40 years 39

IV.—The produce by Mineral Manures without Ammonia, as compared with the produce of the Unmanured land, over four periods of 8 years each 42

V.—Produce of Plots 10 A and 10 B, Ammonia without Minerals; and of Plots 17 and 18, Ammonia in alternation with Minerals; and the bearing of the results upon the question of claims for unexhausted residues 45

VI.—Produce grown by Mixed Mineral Manures, with Salts of Ammonia in various proportions, and with Nitrate of Soda, over four periods of 8 years each, and for comparison the produce by Minerals alone 49

VII.—The unexhausted residue of Manures, as shown by results obtained on Plots 16 A and 16 B: and for comparison on Plot 5, which received Minerals alone 53

VIII.—Comparison between the produce of Farmyard-dung (Plot 2), and Artificial Manure consisting of Minerals and Salts of Ammonia = 86 lbs. of Nitrogen (Plot 7). The former supplying a large amount of organic matter, the latter none 55

IX.—On the Underground Fertility of Plots 2, 3, and 7 58

X.—Summary and General Conclusions 60

Appendix-Tables I.-XXVII. 63-97

REPORT OF EXPERIMENTS

ON THE

GROWTH OF WHEAT.

In the Journal of the Royal Agricultural Society of 1864 we published an article on the growth of wheat for 20 years in succession—1844 to 1863 inclusive—upon the same land. We have now to record the continuation of these experiments over a similar period of 20 years—1864 to 1883.

The 20th crop of the first period—grown in 1863—was much the largest of the whole; and, as will be seen further on, the first crop of the second period of 20 years, grown in 1864, was also the largest of the whole; further, these two crops of 1863 and 1864 were larger than any two crops grown during any of the other 38 years.

The first period comprised a number of seasons of great abundance: the second period a number of seasons of very deficient yield.

In the first period of 20 years an artificial manure applied continuously to the same plot (8 A and B) produced over the last 10 consecutive years an average of 40½ bushels per acre per annum. In the second period of 20 years the same plot, receiving exactly the same manure every year, produced over the last 10 years of that period, an average of only 32¾ bushels, equal an average annual reduction of 7¾ bushels per acre over 10 consecutive years!

Formerly, when the yield was bad, the farmer obtained compensation in the shape of higher prices for his produce, but in this case the larger crops of the first period were sold at considerably higher prices than the smaller crops of the second period. In the first period there was considerable agricultural prosperity, while the second period has witnessed a more severe agricultural depression than any that has occurred during the present century.

An attempt to investigate the growth of wheat under circumstances so totally different from any which have ever previously

arisen, could hardly be carried out without the commission of some errors which experience would have enabled us to avoid. We now know—if we wish to advance beyond the question of the best manure to grow one crop of wheat—that continuity of the same manuring is of supreme importance. With the exception of the plot receiving farmyard dung, and the unmanured plot—neither of which has been altered from the commencement—there is no plot in the field in which some change has not taken place in the manure applied during the early years of the experiment. But in the autumn of 1851, 8 years after the experiments were commenced, the manuring of the field was arranged upon a fixed plan which—with very slight changes in one or two instances—has been continued up to the present time.

Upon the plot receiving farmyard dung, and the unmanured land, no change has taken place during the 40 years; upon most of the other plots, which comprise about 16 experiments, no change has taken place for 32 years.

In our former paper we devoted some time and space to the purpose of considering, and refuting the views held by Baron Liebig with respect to the growth of wheat. All controversy in regard to these once celebrated theories has died out. There is no question at the present time regarding the ingredients in which soils cropped repeatedly with corn are generally deficient; nor is there any question as to what substances must be applied with a view to increasing the produce. A possession of this knowledge enables us to forecast with some degree of certainty—subject of course to the influence of climate—what will be the relative yield of the various manures applied to our experimental crops, for some considerable period in advance.

Coincident with an increase of knowledge in this direction a completely new branch of enquiry has sprung up.

Analysis tells us that a very considerable proportion of the ingredients we apply to grow the crop is not found in the produce. What has become of this unrecovered amount?

Again, the greater part of the crop consists of ingredients which are not supplied. What is the source of these ingredients?

The carbon, which is the source of heat in our fires, is taken out of the earth in the form of coal. If we increase the carbon of our crops by means of artificial manures which do not supply any carbon, does the increase come out of the soil?

If it does, the artificial manures will cease to be effective when all the carbon is exhausted.

Analyses of the water passing through a cultivated field show that while one very important and costly manure ingredient is there in abundance, there are others which are only there in very minute quantities.

Here, then, is a large field of investigation opened.

The soil itself, without external aid from fertilising matter, appears to be capable of producing much more growth than it was formerly credited with, and at the present time, when the provisions for compensation under the Agricultural Holdings Acts involve a distinction between the fertility which is the property of the landlord, and that which belongs to the tenant, investigations which have a direct bearing upon these questions must be both interesting and instructive. While therefore the previous paper dwelt more especially upon the influence of the manure upon the crop, the present article will enter more fully into the question of what takes place within the soil.

We propose to follow the same plan which was adopted on the previous occasion, of giving a short outline of the character of the weather of each year, illustrating its influence upon the crop by a selection of the produce from plots that have been differently manured.

Since the publication of our paper upon the growth of wheat for 20 years in succession, we have published two articles in this Journal; one, in 1868, relating to the average yield of our wheat crops from 1852 to 1868;(1) and the other, in 1880, under the title of "Our Climate and our Wheat Crops," where we traced the character of the climate of several years in which the crops grown were remarkable, either for being very large, or very poor in their yield; it will therefore be less necessary to dwell at any length upon the character of the climate of each separate season, although the subject could not very well be altogether omitted.

Twenty-first Season, 1863–64.

October, November, and December 1863, were warmer than usual, with upon the whole rather less than the average amount of rain. January and February 1864, though including some abnormally warm intervals, embraced longer periods of very cold and wintry weather, which checked forward vegetation; there was considerably less than the average fall of rain in January, and a very slight fall, including snow, in February. In March the rainfall was large—the first half of the month gene-

(1) also one in 1880, giving the record of average yield for 28 years, 1852-3 to 1879-80,

rally warm, the latter half cold—and, upon the whole, the quarter had been very variable, but colder than usual, with many alternations from frost to thaw. April and May were for the most part warm, with less than the average amount of rain; but the end of May and nearly the whole of June were comparatively cold, with little rain. In July and August there was less rain than is usual in these months, but an excess in September. The day temperature generally ranged high in July, but about the average in August and September; whilst the night temperature was somewhat below the average in July, much below in August, and about the average in September. In June and July the dew point was below, and in August very much below the average. The degree of humidity of the air was in June low, in July about the average, and in August considerably below the average.

Thus the winter was very variable, including a good deal of warm, but also much very cold and wintry weather, though with comparatively little rain. The spring, though changeable and wet at the beginning, was, upon the whole, warm and dry; June was cold and dry, whilst the rest of the summer was hot in the day and cold at night, with very little rain, and in August especially a very dry atmosphere.

TABLE I.—SUMMARY of the RESULTS of the TWENTY-FIRST SEASON, 1863–64.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	16 1¾	62·0	1078	1350
2	14 tons farmyard-manure	40 0	62·5	2595	3893
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	32 0¼	61·8	2093	2832
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	33 1	61·7	2182	3287
5A & B	Mixed mineral manure alone	16 3½	62·0	1087	1376
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	31 0½	62·0	1997	3379
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	45 3¼	63·1	3000	4970
9A	Mixed mineral manure, and .. .. .. 500 lbs. nitrate of soda = 86 lbs. N. ..	51 0¼	62·6	3330	5985
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	49 3½	63·5	3292	5588
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	35 1	61	..	..

Although the weather was generally too hot and dry for the lighter class of soils, the crop was a very large one on those of a heavier character. The produce of the plot manured with minerals and nitrate of soda exceeded 50 bushels per acre, and we have therefore the remarkable fact that, in two consecutive years, a crop of over 50 bushels per acre has been grown upon land which has received only artificial manures for more than twenty years.

Twenty-second Season, 1864–65.

After a rather wet September, but a very low aggregate rainfall during the first 9 months of the year, the concluding quarter of 1864 was also characterised by less rain than usual. The deficiency was very considerable in October and December, though there was rather an excess in November. As to temperature, the period was very variable, with a good deal of cold weather. There were occasionally very high winds; whilst the degree of humidity of the air was unusually low in October, and also somewhat low in November and December. In January, 1865, there was a considerable, and in February a slight excess, but in March a deficiency of rain (including snow), though, throughout the quarter, the number of rainy days was small. Excepting the first half of January, the greater part of which was warm, the quarter was almost throughout unusually stormy and cold, with a good deal of snow; March in particular was generally exceptionally cold and inclement. In April and June very little rain fell; whilst in May and July there was an excess, and in August a very great excess. In September, however, the rainfall was exceptionally small. April, May, and the beginning of June, were much warmer than the average, but the remainder of June was variable, and, upon the whole, rather cold. The mean temperature of the quarter, and especially of April, was, however, the highest on record for that period of the year; and the air was uniformly much drier than the average, as the rain which fell was not much distributed, but came for the most part in heavy showers. July, with an excess of rain, was also warmer than usual. The greater part of August was not only extremely wet, but also rather colder than usual; whilst September was both the driest and hottest on record, and—notwithstanding the comparatively low temperature of August—the average heat over the whole period of six months has never been equalled. In each month too (excepting August, when it was very high) the degree of humidity of the air was generally low.

The winter of 1864–5, though variable, was therefore, upon

the whole, very cold, stormy, and inclement, and the early spring was unusually cold and backward. Later in the spring the weather became very warm with a dry atmosphere, and towards the end, some heavy rains fell. The combined conditions brought the crops very rapidly forward. June was also dry, hot at the beginning, though afterwards comparatively cool; July was hot, with a good deal of rain, but, upon the whole, a dry atmosphere; the greater part of August was cool and very wet, but the remainder, and September, very hot and dry, favouring the rapid completion of the hitherto much retarded harvest work. Thus, after a severe winter and late spring, the growing period was characterised by great heat, dryness of atmosphere, and a deficient amount and distribution of rain; the ripening period by an excess of rain, followed, however, by an eventually favourable, though late harvest time.

TABLE II.—SUMMARY of the RESULTS of the TWENTY-SECOND SEASON, 1864–65.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks	lbs.	lbs.	lbs.
3	Unmanured	13 1½	60·6	828	1033
2	14 tons farmyard-manure	37 0½	61·5	2384	3100
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	25 0½	59·6	1649	2385
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	29 2½	59·5	2005	3137
5A & B	Mixed mineral manure alone	14 0½	60·9	915	1176
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	24 3½	60·9	1605	2021
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	40 1	61·6	2580	3669
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	44 0½	61·1	2881	4682
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	43 2½	61·4	2833	4600
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	30 2½	61·0	..	..

The wheat crop of 1865, although much inferior to that of the two preceding years, was still above the average. The highest produce in the field was on the Mixed Mineral Manure and Nitrate Plot, which yielded 44 bushels per acre, weighing 61 lbs. per bushel. The plot receiving farmyard dung gave 37 bushels per acre, which is considerably above the average of this plot.

Twenty-third Season, 1865–66.

The very warm and dry weather of September, 1865, extended through the first week of October, and, although there were a few cold intervals, the temperatures of the three concluding months of the year ruled higher than the average, December especially being unusually warm. The period included however very great fluctuations in barometric pressure, and some extremely severe storms of wind; whilst in October an excessive, in November a full, but in December a deficient amount of rain fell. January and the first half of February (1866) were also unusually warm, though in January there was a heavy fall of snow, which however rapidly thawed, and the whole period was very wet. A cold and drier period then set in, and extended to the middle of March, checking the hitherto much too forward vegetation. After this, to the end of the quarter, the temperatures, though variable, ruled, upon the whole, very high, and there was a full amount of rain. The beginning of April was cold and rather wet, and the remainder considerably warmer and drier than the average. May was, throughout, unusually cold both by day and night, and there was a deficiency of rain. June was changeable, but included a good deal of hot weather, which raised the mean temperature above the average, and during the month a considerable excess of rain fell. The beginning of July was cold and wet; then followed a week of hot and dry weather, but, from about the middle of the month to nearly the end of September, the weather, with the exception of a few short intervals, was generally cold, with a good deal of rain and wind in August, and an excessive, and almost continuous fall in September. October was, however, upon the whole, warmer and drier than usual. In June, July, August, September, and October the degree of humidity of the air was generally high.

Thus, after a very wet and comparatively warm autumn, the winter was, until the middle of February, unusually warm, with a great deal of rain, inducing premature luxuriance of grass and winter sown crops; then came a month of cold and dry weather, checking growth. The remainder of the spring was at first very variable, but May was unusually cold and dry. The early summer was changeable, but mostly warm, with a good deal of rain; and the ripening and harvest periods were almost continuously cold and rainy, with a moist atmosphere, but with occasional high and drying winds.

The wheat crop of 1866 was one of inferior yield under all the different classes of manures, the highest produce of any one plot not reaching 33 bushels; while the estimated yield of the

crop of the country was 25 bushels per acre, calculated upon a a weight of 61 lbs.

TABLE III.—SUMMARY of the RESULTS of the TWENTY-THIRD SEASON, 1865–66.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	12 0½	61·3	777	1269
2	14 tons farmyard-manure	32 2½	61·7	2070	4058
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	26 1	61·2	1693	2792
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	30 3	59·9	1979	4682
5A & B	Mixed mineral manure alone	13 1	60·9	838	1465
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	20 2	61·0	1294	2248
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	29 3¾	61·0	1891	3884
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	32 2	60·6	2061	5316
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	32 0½	60·1	2054	5312
	Estimated average for the United Kingdom reckoned 61 lbs. per bushel	25 0½	61·0	..	..

Twenty-fourth Season, 1866–67.

The concluding quarter of 1866 was generally warmer than the average, though it included some cold intervals. There was somewhat less than the usual aggregate amount of rain, though a good deal fell within a short interval about the middle of November, causing floods, and hindering autumn sowing in some localities. In January, 1867, the fluctuations were very great; extreme cold and heavy falls of snow, alternating with rapid thaws, warm weather, heavy gales, and a good deal of rain. The last week of January and almost the whole of February were unusually warm, with a large amount of rain at the beginning, and a moderate quantity over the rest of the period. March, again, was almost to the conclusion very cold and wintry, with a good deal of snow. Throughout the quarter there was a succession of gales and wind. Owing to the severe weather of March, the growth of winter sown crops was checked; and owing partly to the wet, and partly to the frost, the preparation of the land for spring sowing was much retarded. April, and the beginning of May, were very unsettled; stormy, rainy, and changeable as to temperature, but, on the average,

warmer than usual. Later in May, besides some very warm weather, there was a longer period that was extremely cold, with a dry atmosphere, and frosty nights, which much checked vegetation, though, during the month, there was rather more than the average fall of rain. June was comparatively dry, very changeable as to temperature, but on the average colder than usual. The cold weather continued throughout July and the beginning of August, and the period was generally sunless and cloudy, with an excess of rain in July, which fell very heavily towards the end of the month. The crops in consequence were much laid, and in some cases were inundated. The remainder of August, and September, were much finer, and rather warmer than the average, though there was more than the average fall of rain, which however was not much distributed, but fell for the most part in considerable quantities at a time.

Thus, the early winter was, upon the whole, warmer and drier than usual; then came intervals of severe frost, snow, and heavy gales, followed by several weeks of very warm weather, with a good deal of rain. The early spring was very wintry and stormy, and growth and spring sowing were alike retarded. Later on the temperature was very changeable, being at first warmer, afterwards unseasonably cold, and frequently stormy and rainy. The rest of the growing, as well as the early ripening period, was changeable, though for the most part unseasonably cold, cloudy, and sunless, with a great deal of rain, and occasionally very heavy falls which much laid the crops. The harvest-time, though late and including some heavy rains, was however upon the whole not unfavourable for the greater portion of the Midland, Southern, and Eastern districts.

With a wet autumn, a winter alternately very mild and very severe, a spring with alternations of extreme heat, cold, frost, and wet, and a summer with a good deal of sunless weather, and occasional violent storms of wind and rain which laid the crops, the conditions were certainly not of a nature to justify the expectation of a productive harvest. Yet, both before and after the favourable change at harvest time, some writers in the 'Times' gave very sanguine views of the crops of the country at large. The records in the agricultural papers were, however, much less favourable, and the results obtained at Rothamsted led us to the conclusion that the general wheat crop would not be less than 20 per cent. below an average. Subsequent experience showed that this unfavourable estimate was only too well founded.

After the record of the weather of 1866–7 a good wheat crop could not be expected. Violent changes from heat to cold—

the latter predominating—accompanied by much rain, are not favourable to growth.

TABLE IV.—SUMMARY of the RESULTS of the TWENTY-FOURTH SEASON, 1866–67.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	8 3½	56·1	532	978
2	14 tons farmyard-manure	27 2½	61·4	1755	3186
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	18 0½	57·9	1123	2023
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	22 0½	57·4	1392	3246
5A & B	Mixed mineral manure alone	9 1	59·4	580	1033
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	15 3	60·5	1008	1723
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	22 0½	61·0	1417	2762
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	29 0½	59·9	1855	4918
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	30 1½	60·7	1952	4196
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	21 0	61·0	..	..

We had, both on the unmanured plot, and on all the other plots, no matter what description of manure had been applied, a low yield. The unmanured produce was less than 9 bushels per acre, and, except in the spring sown crop of 1853, no such low produce has been obtained. The highest produce in the field was below 31 bushels, and the average yield of the crop of the country was estimated at 21 bushels, of the calculated weight of 61 lbs.

Twenty-fifth Season, 1867–68.

October, 1867, was very variable as to temperature, upon the whole colder than usual, with comparatively little rain, but occasional high winds. There was unusually little rain in November, and the weather was for the most part clear but cold, and very favourable for working the land and sowing. December was characterised by great and rapid variations of temperature and barometric pressure, with some extremely heavy gales; occasionally frost, snow, and sleet, at other times very warm weather; in the aggregate there was a full amount of rain, and throughout the month agricultural operations were much im-

peded. The first eleven days of January, 1868, were very cold; but from that time to the end of the quarter (indeed to the end of the summer), the weather was unusually warm. There was a considerable excess of rain, and there were several gales of wind in January; but only a moderate amount of rain fell in February and March. In these months vegetation became very forward, and the weather was generally favourable for working the land and for spring sowing. April, May, and June, again, were all considerably warmer than the average. The average temperature of April had, however, frequently, and that of each of the other months occasionally been exceeded in the corresponding months of other years; but the average temperature of the three months together had only once been exceeded in any corresponding three months for 98 years (the period for which records are available), namely, in 1865, when, though April was hotter, May and June were not quite so hot as in 1868. The average temperature of the whole period, from the middle of January to the end of June, was only exceeded in 1822. Concurrently with this long continued warm weather, there was a great excess of rain in January, and only a moderate amount in February and March; there was a small excess in April, a deficiency in May, and a very great deficiency in June. Temperatures in excess of the average also prevailed almost continuously throughout the succeeding quarter, namely, to the end of September. July, in particular, was excessively warm, with at the same time a great and continued deficiency of rain; August was also warmer than the average, but with a good deal of rain; and September was still warmer than August, with a deficiency of rain. In no year of the previous 98 had the temperature so far exceeded the average for so long a corresponding period, as that from the middle of January to the end of September of this year, 1868. The total rainfall of the nine months was not much below the average; but the amount which fell was excessive in January, as also in April and in August, whilst it was deficient in each of the other months of the period, and more especially in those of the greatest heat, namely May, June, and July. The degree of humidity of the atmosphere was also lower than the average in each of the nine months from January to September inclusive, especially in June, still lower in July, and considerably lower in August and September.

The characters of this extraordinary season may be briefly summarised as follows:—After a favourable autumn seed time, the first half of the winter was very variable, including some very warm, but more stormy, wet, snowy and frosty weather. From that time to after harvest, the temperature was almost always

above the average, and very greatly so in the summer months of June and July; whilst, after a favourable spring seed time, there was a sufficiency of rain in April to give a fair start to early-sown crops; but, from that time until the harvest was nearly over, throughout the Midland, Southern, and Eastern districts of the country, the excessively high temperature was accompanied by a drought of unusual severity, both as regards the length of its duration, and the great deficiency of rain, while at the same time the atmosphere was very dry.

With the favourable autumn seed time, the area under wheat was over the average. In the spring the plant was generally good, the harvest was very early, and finally the crop was reported to be considerably above the average in both quantity and quality on good and well-farmed soils; on light and poorly farmed land, on the other hand, the crop suffered much from the heat and drought. Still, the aggregate wheat crop of the country was supposed to be about 20 per cent. over the average in quantity, and also of above average quality.

TABLE V.—SUMMARY of the RESULTS of the TWENTY-FIFTH SEASON, 1867–68.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.				
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	16 2½	61·0	1054	973
2	14 tons farmyard-manure	41 3	61·6	2604	4190
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	24 3	61·9	1627	2163
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	27 1	62·0	1799	2742
5A & B	Mixed mineral manure alone	17 2½	62·8	1135	1946
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	28 1½	62·8	1835	2569
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	39 3½	61·1	2468	3849
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	47 3½	61·1	2970	5180
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	46 2	62·0	2932	4808
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	34 0	61·0	..	..

Although considerably higher yields have been obtained upon some plots than those which were grown this year, still, the yield from all the different manured plots has rarely been exceeded; the mean obtained, 34 bushels, confirming the verdict of the country regarding the general excellence of the crop.

Twenty-sixth Season, 1868–69.

The extraordinary warm period of nearly nine months' duration ended with September 1868. October and November were throughout, with very few exceptions, colder than usual both by day and night; whilst in October there was a deficiency of rain, and in November a very great deficiency. December, on the other hand, was almost throughout very much warmer than the average, with a great excess of rain, some violent gales of wind, very variable, but, upon the whole, very low barometric pressures, and a high degree of humidity of the atmosphere. The average temperature of December had indeed been exceeded only twice during the preceding ninety-eight years; namely, in 1806 and 1852. With the exception of a week after the middle of January (1869), the very warm period continued until the end of February, completing three winter months of average temperature about 6 degrees higher than the average of ninety-eight years. There was, again, a considerable excess of rain in January, and a slight excess in February. March, on the contrary, was several degrees colder than the average, with about, or less than, the average amount of rain. Early in April warm weather set in, and lasted till nearly the end of the month, the temperature during this period being several degrees higher than the average, whilst the fall of rain was generally under the average. May and June were, with few exceptions of short duration, very much colder than the average. Towards the end of May the cold was very extreme for the season, the greater part of June was also unusually cold, both by day and night; and in May there was a considerable excess, though in June a deficiency, of rain. Early in July there was again a change to warm weather, which lasted till the end of the month, during which there was very little rain. The first three weeks of August were unseasonably cold and showery, though the total amount of rain was comparatively small; but the concluding week of the month was very bright and hot. Then came a short period of cold weather, but the remainder of September was warm though stormy, with a good deal of rain. In April, May, and June, the degree of humidity of the air ranged high, especially in May; in July it was about the average, but in August and September it was below it

To sum up the characters of the season: The heat and drought of the spring and summer of 1868 were followed by a warm and dry September, and a cold and dry October and November provided a good autumn seed-time. The three winter months were very warm and—December and January especially—very wet, which brought the autumn sown crops rapidly forward, and

provided an unusual amount of winter grazing, which greatly compensated for the previous deficiency. Owing to the condition of the land, spring sowing was retarded. The weather in March was both dry and cold, and in consequence vegetation was much checked; a rapid recovery however took place under the influence of very warm, though somewhat dry, weather in April. The remainder of the spring was very cold, and also wet; June, again, for the most part was cold, and July warm; most of August was cold, but the latter part of the month and September were hot, while the summer was comparatively dry, though the harvest-time was somewhat unsettled.

TABLE VI.—SUMMARY of the RESULTS of the TWENTY-SIXTH SEASON, 1868–69.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.				
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	14 1	56·1	848	1350
2	14 tons farmyard-manure	38 1	56·9	2256	3937
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	20 1	54·9	1210	2265
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	24 0½	54·6	1452	3475
5A & B	Mixed mineral manure alone	15 3	56·9	942	1601
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	21 2½	57·2	1309	2265
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	28 1½	57·5	1760	3212
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	39 0	57·1	2368	4930
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	34 3	57·2	2096	3918
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	27 0	61·0	..	..

The extreme fluctuations of temperature which marked this season are visible in the very low quality of the produce: in not one experiment does the weight of the bushel reach 58 lbs., while the yield of the crop generally was large, but when calculated upon a standard of 61 lbs. per bushel, it was slightly below an average.

Twenty-seventh Season, 1869–70.

Until the middle of October the autumn of 1869 was for the most part warm, with a good deal of rain. From that time until the end of the year the weather—though including some rapid

fluctuations, some very warm days, and a warm period of more than a week in the middle of December—was very cold and inclement, and especially wintry towards the end of October. There were numerous gales throughout the quarter; while there was less rain than usual in October, about the average in November, and a considerable excess in December. The falls were heavy and continuous at the end of November, and again in the middle of December; while the drains in the experimental wheat-field ran frequently from November 28th, 1869, to January 1st, 1870. The first three months of 1870 were characterised by frequent alternations of warm, and very cold weather—the colder periods being, however, much the longer, and sometimes very severe; snow was very frequent, but the rain gauge indicated a deficient fall in January, in some localities a deficiency in February, but a very heavy fall early in the month, and an excess in March. From early in April to near the end of the month the weather was very warm and dry; then followed about a fortnight of cold and cloudy weather, from which time until nearly the end of June it was again very warm, sunny, and dry—the three months together being not only warmer than the average, but very unusually deficient in rain. The day temperature especially was high, though the night temperature in April and May was low, but in June high. The end of June and the beginning of July were cold and variable, but the remainder—indeed, nearly the whole of July, as well as the first half of August—was very warm. Then, to the end of September, a period of about six weeks, the temperature was generally below the average, though the weather continued fine. Thus, the period of drought, which had commenced with April, continued to nearly the end of August, and even in September there was less than the average fall of rain. The large deficiency of rain throughout five consecutive months was, moreover, accompanied by great dryness of atmosphere—the degree of humidity of the air being in April unusually low, and in May, June, July, and August, also considerably below the average.

The autumn of 1869, though, as the details show, frequently cold, boisterous, and inclement, was upon the whole not unfavourable for getting in the seed. The winter, though changeable, included a great deal of very cold weather. In the early spring both field-work and vegetation were very backward, and at the end of April grass land was very brown and bare. From the beginning of April until harvest the weather—with few exceptions of short duration—was warmer than usual, with a great deficiency of rain, and a very dry atmosphere.

The combined heat and drought were even more extreme during the months of May, June, and July 1868, than during

the corresponding months in 1870; but in the latter year the deficiency of rain commenced a month earlier, and continued later than in 1868. The grass crops in consequence suffered much more in 1870; and, for a parallel, we must go back as far as 1844. As in the two preceding years (1868 and 1869), the reports of the cereal crops of the country were very variable, but for very opposite reasons in the years of heat and drought, 1868 and 1870, as compared with 1869.

TABLE VII.—SUMMARY of the RESULTS of the TWENTY-SEVENTH SEASON, 1869–70.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.				
		Dressed Corn.			Total Corn.	Straw and Chaff.
		Quantity.		Weight per Bushel.		
		bush.	pks.	lbs.	lbs.	lbs.
3	Unmanured	14	3½	61·8	956	1046
2	14 tons farmyard-manure	36	2	63·4	2359	2733
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	21	2½	60·8	1420	1627
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	26	1½	61·3	1735	2080
5A & B	Mixed mineral manure alone	18	2½	62·6	1203	1360
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	30	1½	63·1	1980	2354
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	40	2½	63·3	2620	3216
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	45	2	62·7	2940	3911
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	45	1	63·8	2966	3667
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	30	0	61·0	..	..

Although the yield of wheat in this exceedingly dry season was generally lower than in 1868, the weight of the grain was in some cases considerably higher, reaching in one experiment nearly 64 lbs. per bushel.

The ravages of wireworm were very general throughout the country; this considerably reduced the yield of the crop, which otherwise would have been a large one.

Twenty-eighth Season, 1870–71.

In October 1870 the changes of temperature were very frequent, giving however about the average for the month; and there was a slight excess of rain. The first 19 days of November were for the most part cold, while the remainder was warm, but the average for the month was low, and there was a con-

siderable deficiency of rain. There were about 10 days of very warm weather in the middle of December, but the beginning and end of the month were cold; the latter extremely so, with a good deal of snow and cold wind; the average for the month was 5 or 6 degrees below the average for 99 years; and the rain and melted snow indicated a considerable excess of fall. January 1871, with the exception of a few days in the middle of the month, was cold; and at the beginning, and for nearly a fortnight at the end, the weather was extremely severe. From early in February until the middle of March the weather was very mild, but from thence to the end of the month the temperature was very variable. There was a full amount of rain (or snow) in January, but a deficiency in both February and March; though the melting of the snows of January, succeeded by frequent rains early in February, caused floods in many parts. April, May, and June were—with the exception of the latter half of April, which was warm, with a good deal of south-west wind and rain—unusually cold, with a great deal of east or north wind, or some compound of the two; and there was an excess of rain in April and June but a deficiency in May; June especially being very unseasonably cold and wet. July, excepting about a week after the middle of the month, was cold, with a considerable excess of rain; but, from early in August to about the middle of September, there was a period of six weeks of warm and genial weather, from which time till the end of September, it was again very cold, wet, and stormy. August was not only warm, but there was very little rain, whilst in September there was, towards the end of the month, a great excess of rain. The degree of humidity of the air was high in April and June, rather high in July, rather low in May, very low in August, and low in September.

The autumn of 1870 was thus changeable as to temperature, being upon the whole, cold; wet prevailed during the first half of September, and also of October, but afterwards the weather was comparatively dry and favourable for field work. The greater part of the winter was extremely severe, with a good deal of snow and very cold winds; the remainder was mild and very wet, retarding field work and spring sowing. Winter corn was very backward, and in many cases injured, pastures were bare, and vegetables very scarce. The hard winter had, however, killed many insects, and March was favourable for field work and sowing; but, with the exception of the latter half of April, the remainder of the spring was cold and backward. The rest of the active growing period, excepting one or two intervals of short duration, was cold, bleak, and very wet. In the greater part of England, however, August and the early

part of September being warm and dry, much aided the ripening and getting in of the crops; but the latter half of September was cold and wet.

TABLE VIII.—SUMMARY of the RESULTS of the TWENTY-EIGHTH SEASON, 1870–71.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	9 1½	54·8	615	1100
2	14 tons farmyard-manure	38 3½	60·0	2498	4506
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	10 0½	53·8	675	1252
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	17 2½	52·4	1093	2425
5A & B	Mixed mineral manure alone	11 3½	56·6	773	1435
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	17 0	56·5	1089	2297
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	22 1	56·7	1512	3085
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	34 1½	58·6	2228	4909
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	27 2½	57·7	1843	3933
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	24 0	61·0	..	..

Both in quantity and quality the wheat crop of this season was much below an average. The dunged land, which yielded nearly 39 bushels, weighing 60 lbs. per bushel, shows, what may be noticed generally throughout the experiments, that while the crops on the dunged land are able to resist the influence of bad weather better than those grown by artificial manures, they cannot, in very favourable seasons, attain the produce which is reached by the artificially manured crops.

The estimated produce of the selected experiments gives 24 bushels per acre, at 61 lbs. per bushel.

Twenty-ninth Season, 1871–72.

October, November, and December, were all months of excessive cold, with very little rainfall. Mr. Glaisher observed that the quarter had been remarkable for the longest continuance of low temperature in November, and the first half of December, that had occurred in this century.

This was followed by nearly three months of very warm weather, which lasted until the middle of March. The 17th of

March was 9½ degrees above the average, and the 21st was 12 degrees below it. October, November, and December, were dry months, while in January and March the rainfall was in excess. April was a warm month. All the month of May and the first half of June were cold, the remainder of June was warm. The rainfall was below the average in April and June, but rather above it in May. The first week in July was excessively hot; this was followed by ten days of cold weather, after which came eleven days of very great heat. August was cold and wet, while the rainfall in July was slightly below the average. In August and September frequent and heavy rains, and thunder-storms, interrupted harvest operations.

TABLE IX.—SUMMARY of the RESULTS of the TWENTY-NINTH SEASON, 1871–72.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	10 2¾	59·0	705	1152
2	14 tons farmyard-manure	32 1½	60·7	2046	3761
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	18 0	56·8	1178	2442
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	23 1½	55·5	1434	3210
5A & B	Mixed mineral manure alone	12 3½	60·0	835	1331
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	20 2	60·2	1304	2567
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	29 2¾	60·2	1937	3827
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	40 2¾	60·0	2565	6527
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	35 2½	60·5	2324	5071
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	24 0	61·0	..	..

The season of 1872 was much more favourable for artificial manures than the season of 1871, their produce having in one instance reached 40 bushels per acre; while the weight per bushel over the whole field was very much higher than in 1871: the yield of the crop of the country, however, was estimated to be considerably below an average.

Thirtieth Season, 1872–73.

October was cold until the 25th, a warm period then set in which lasted until the 9th of November, when the weather again became cold. The first part of December was cold, the

latter part unusually warm, and all the three months were excessively wet, over eleven inches of rain having fallen at Greenwich during that period.

The first fortnight in January was warm, and the remainder of the month about an average temperature. February was rather cold, and March about an average. The rainfall was slightly in excess in January and February, and slightly below the average in March. April was cold, especially towards the latter part of the month. From the 22nd of April to the 18th of June the mean temperature was 2¼ degrees below the average, the remainder of June was warm. April and May were very dry months, while the rainfall in June was above the average. July was cold up to the 19th, when a few days of excessively hot weather occurred, followed again by cold. The temperature of the month was on the whole above the average.

The rainfall in July was below the average. August was alternately hot and cold, with a great deal of rain; the character of the season was one of great fluctuations, as the temperature during the winter was very warm, and the spring and early summer were very cold, while there was a good deal of rain to interfere with the ripening of the corn.

TABLE X.—SUMMARY of the RESULTS of the THIRTIETH SEASON, 1872–73.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	11 2½	57·0	701	902
2	14 tons farmyard-manure	26 3	58·1	1622	2463
10A	400 lbs. ammonium-salts = 86 lbs. N. ..	19 2½	56·1	1173	1635
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	21 3½	54·9	1303	2358
5A & B	Mixed mineral manure alone	12 2½	56·9	763	1043
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	15 3½	57·1	960	1520
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	21 3½	57·2	1323	2021
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	35 3½	57·1	2160	3932
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	27 2	56·9	1643	2664
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	22 2	61·0	..	..

The history of the season is quite sufficient to account for the badness of the wheat crop; the produce of the farmyard

dung did not quite reach 27 bushels, and the highest produce in the field only amounted to 35¾ bushels per acre; while the highest weight per bushel in the field was 58 lbs. The crop of the country was estimated to be greatly below an average.

Thirty-first Season, 1873–74.

The temperature in October fluctuated very much; sometimes it was much above the average warmth, and at others it was very cold; on the whole, however, the temperature was colder than the average, while in November it was some degrees warmer than the average. December was above the average. The rainfall in October was slightly below the average, in November slightly above it; while in December hardly any rain fell during the month.

TABLE XI.—SUMMARY of the RESULTS of the THIRTY-FIRST SEASON, 1873–74.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.				
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	11 1¾	58·3	694	990
2	14 tons farmyard-manure	39 1	60·2	2431	4439
10A	400 lbs. ammonium-salts = 86 lbs. N. ..	25 1	56·5	1476	1977
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	21 2	57·5	1269	2166
5A & B	Mixed mineral manure alone	13 0	59·1	794	880
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	25 3¼	59·6	1556	2221
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	39 1¾	59·8	2449	4645
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	38 0¾	60·4	2409	5012
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	40 2	59·9	2554	6063
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	29 1	61·0	..	..

The temperature of January, February, and March was in excess of the average. January was unusually warm, the excess of temperature being 5½ degrees during the whole month. The rainfall was below the average in each of the three months, being not more than one-half the usual fall. April was an exceedingly warm month, the temperature being on several days 10 to 13 degrees over the average. The first three

weeks of May were exceedingly cold; this was followed by very warm weather which continued until the 11th of June, after which cold weather prevailed until the end of the month. April was a dry month; May excessively dry, the rainfall at Greenwich not amounting to half an inch. The rainfall in June was slightly over the average. In July there were frequent and severe fluctuations of temperature, but on the whole the month was hotter than usual.

To sum up—the climate of the wheat year of 1873–74 may be said to have been one of unusual dryness from beginning to end; of high temperature in the autumn, winter, and early spring, but after this the weather was cold until July.

The yields from the best artificial manures and the dung were very similar, amounting to from 38 to 40 bushels per acre, and the quality of the corn was fairly good. The yield of the crop of the country was estimated to be over an average.

Thirty-second Season, 1874–75.

The month of October, and November until the 20th was warm, the temperature being nearly 2 degrees over the average; but on the 20th a bitterly cold period set in and continued until the end of December. The mean temperature of the period was more than 6·6 degrees below the average—some days being 10 and one day 14 degrees below it. The rainfall in October was slightly in excess of the average. November and December were both dry months, especially the latter, and the total rainfall during the year was 20 inches, which is 5½ inches below the average. January was exceedingly warm, the mean temperature of the month being 6¾ degrees over the average; this was followed by a very cold period which continued until the end of March. The rainfall was in considerable excess in January, and below the average in the two succeeding months. April was a very cold month, and on the 27th vegetation was very backward; but this cold was followed by a warm growing period which continued until the 10th of June, when vegetation was as forward as usual. The remainder of June was cold. The rainfall in April and May was slightly below the average, and in June slightly above it. The cold weather which set in on the 10th of June continued all through the month of July and until the 5th of August, when there came a warm period which lasted for a long time. The rainfall of July was excessive, causing great floods and doing much injury to the hay and corn crops; in some districts from 3 to 5 inches of rain fell in one day.

TABLE XII.—SUMMARY of the RESULTS of the THIRTY-SECOND SEASON, 1874–75.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.				
		Dressed Corn.			Total Corn.	Straw and Chaff.
		Quantity.		Weight per Bushel.		
		bush.	pks.	lbs.	lbs.	lbs.
3	Unmanured	8	2½	60·0	567	1008
2	14 tons farmyard-manure	28	3½	60·6	1890	3719
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	12	3	54·5	786	1574
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	16	2	55·7	1050	2363
5A & B	Mixed mineral manure alone	9	1	59·4	590	1125
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	16	1¼	60·3	1065	2008
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	25	3½	59·5	1688	3422
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	30	2	57·9	1965	4747
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	29	3¾	58·2	1937	4323
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	22	3½	61·0	..	..

The season was remarkable for the great floods which prevailed all over England in the month of July (1875); these did considerable damage to the wheat crop, and both on the dunged and the artificially manured land the yield was about 10 bushels per acre less than that of the previous year. The yield of the country was estimated to be greatly below an average.

Thirty-third Season, 1875–76.

October was generally cold and wet; November up to the 19th was rather warm; this was followed by a period of extremely cold weather, with a considerable fall of snow, which, owing to the high winds, did not cover the wheat, but drifted to the hedges. The weather of this period was very similar to that of 1874; but this year the cold came to an end on the 17th of December, when warm weather prevailed until the close of the year.

The rainfall was greatly in excess in October, slightly so in November, and below the average in December. January was alternately very warm and extremely cold, the cold, however, predominating; the middle of February was also very cold, but the latter part of the month and the beginning of March were unusually warm; this was followed by three weeks

of very cold weather, but the last three days of the month were very warm. The rainfall in January and February was below the average, while in March it was slightly above it. The first nine days in April were excessively warm, but the weather which followed was very severe, and from the 11th to the 14th a great amount of snow fell; the last ten days of the month were warm. Throughout the month of May the cold was excessive, and continued so up to the 18th of June; the remainder of June was warm. The rainfall during the three months was much below the average, being not more than 3½ inches over the whole period. The months of July and August were exceedingly fine and hot, and in the middle of July several days were recorded on which the temperature was over 90 degrees; very little rain fell during this month.

TABLE XIII.—SUMMARY of the RESULTS of the THIRTY-THIRD SEASON, 1875–76.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	8 0½	59·0	500	642
2	14 tons farmyard-manure	23 3½	62·4	1545	2140
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	12 0½	57·2	719	922
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	13 0	56·3	766	1217
5A & B	Mixed mineral manure alone	10 2	59·2	645	785
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	15 2¾	62·1	1022	1297
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	23 2	63·0	1582	2212
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N... ..	33 1¼	62·7	2255	3584
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	29 2¼	62·9	1975	2936
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	25 0	61·0	..	..

The quality of the crop of 1876 was much over an average, reaching in one case to 63 lbs. per bushel, but the yield was bad, the highest produce in the field only slightly exceeding 33 bushels per acre. The produce of the dunged plot was exceptionally bad, amounting to less than 24 bushels per acre. The crop of the country was considered to be superior to that of 1875, but still was below an average.

Thirty-fourth Season, 1876–77.

October was very warm and wet till the 20th; the remainder of the month was dry and cold. In November the cold period continued until the 13th; from that time until the end of the year the weather was very warm. The rainfall in November was rather over the average, and the wettest December of which there is any record followed. The rainfall in London was slightly below, and at Rothamsted slightly above 6 inches. In January and February the temperature was much above the average, and rain fell almost continuously. The first three weeks of March were cold; the latter part of the month was warm, and the rainfall was a little over the average. The first part of April was warm, but on the 11th a cold period set in which continued until the end of the month. May was a remarkably cold month; during many nights there was frost, and in some places the thermometer went down to 13, that is to say, 19 degrees below freezing-point! June was a very hot month. In April the rainfall was in excess, and in May and June it was below the average. July was a very cold month, with an average rainfall. August was a warm month until the 21st, after that, and during the whole of September, the weather was excessively cold. Mr. Glaisher stated that the mean temperature of September 1877 was the lowest recorded for 74 years. The rainfall was in excess in August, and deficient in July and September.

TABLE XIV.—SUMMARY of the RESULTS of the THIRTY-FOURTH SEASON, 1876–77.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	8 3½	58·9	543	748
2	14 tons farmyard manure	24 0½	59·1	1481	2266
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	17 0¾	57·5	1031	1322
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	27 2¾	58·0	1654	2540
5A & B	Mixed mineral manure alone	11 2¾	57·1	688	882
6A & B	Mixed mineral manure, and 200 lbs. ammonium-salts = 43 lbs. N.	14 2¼	58·2	876	1176
7A & B	Mixed mineral manure, and 400 lbs. ammonium-salts = 86 lbs. N.	19 3½	59·2	1213	1835
9A	Mixed mineral manure, and 550 lbs. nitrate of soda = 86 lbs. N.	40 0½	57·9	2383	3852
8A & B	Mixed mineral manure, and 600 lbs. ammonium-salts = 129 lbs. N.	24 3	59·2	1510	2244
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	26 2	61·0	..	..

Although the yield of one of the artificially manured plots reached 40 bushels per acre, the quality of the wheat was very inferior. The produce of the unmanured and dunged land was almost the same as that of 1876, being respectively 8¾ and 24 bushels per acre. The crop of the country, although below the average, was estimated to be rather better than that of 1876.

Thirty-fifth Season, 1877–78.

October was on the whole a fine dry month, but on the 14th there was a great gale which caused much damage. November was wet, and another severe gale occurred on the 11th. December was generally warm, with an average amount of rain. The temperature of the quarter was slightly above, and the rainfall slightly below the average. Up to January 25th the weather was exceedingly warm; after that date a cold period set in which continued until the 12th of February. From February 13th until March 13th, the weather was unusually mild, the temperature sometimes exceeding 60 degrees; a few days of cold weather followed, succeeded by four days of great warmth. On March 23rd the weather became bitterly cold with heavy falls of snow and severe frosts which continued until April 10th. On that and the following day a great fall of rain occurred amounting in some places to two and three inches in twelve hours. The whole month of April, after the 10th, was

TABLE XV.—SUMMARY of the RESULTS of the THIRTY-FIFTH SEASON, 1877–78.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	12 1½	59·0	776	1081
2	14 tons farmyard-manure	28 1	60·9	1890	4042
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	27 1½	59·5	1708	2762
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	23 1½	56·9	1408	2897
5A & B	Mixed mineral manure alone	14 1½	58·8	900	1322
6A & B	Mixed mineral manure, and 200 lbs. ammonium-salts = 43 lbs. N.	22 3	60·8	1446	2944
7A & B	Mixed mineral manure, and 400 lbs. ammonium-salts = 86 lbs. N.	31 1	60·6	2065	4952
9A	Mixed mineral manure, and 550 lbs. nitrate of soda = 86 lbs. N.	37 0¾	59·2	2333	5624
8A & B	Mixed mineral manure, and 600 lbs. ammonium-salts = 129 lbs. N.	38 0½	60·3	2469	6173
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	30 0	61·0	..	..

warm and wet. May was warm and wet up to the 15th, when a cold period set in which continued until June 19th; the remainder of June was very hot. The rainfall of the quarter was more than 13 inches, being about twice the ordinary fall. July was rather cold up to about the middle of the month, but the latter half was very hot, and fortunately dry weather prevailed throughout the month. Some heavy thunderstorms occurred in the beginning of August and the whole month was unsettled.

Although on the nitrate plots the produce of grain did not reach the standard of 1877, still the general yield of the crop was very much better. The unmanured land—which for the last three seasons had not reached 9 bushels—was over 12 bushels, and the dunged plot yielded 4 bushels per acre over the produce of the last two years. It was estimated that the crop of the country was above the average.

Thirty-sixth Season, 1878–79.

Up to October 21st the weather was fine and warm, but on the 22nd it became cold and wet and remained so until December 6th, when severe frosts set in which continued until the 26th. After this the weather became unusually warm.

The character of the quarter may be summarised as follows. A good seed time, followed by intensely cold, wet weather which hardly ceased until the year ended. In some days in December the temperature was 17 degrees below the average, and the whole month was 6 degrees below the average.

January was one of the coldest months ever recorded, the thermometer during the whole month being below 32° F.; snow covered the ground, the days were nearly sunless, and the wind N., N.E. February was also very cold, with a great excess of rain, and a great deal of snow. March was first warm, then cold, and on the 21st very cold with snow; but the last days of the month were warm. The five months ending March 31st may be described as exceedingly cold with much rain and snow. The next three months may be summed up in a few words as cold, wet, and sunless; while Mr. Glaisher further informs us that for lowness of temperature the eight months ending with June have only been once exceeded during the one hundred years and upwards which have elapsed since the first records were kept at Greenwich.

July was dull, cold, and sunless; rain fell every day during the first half of the month, and frequently afterwards, sometimes mixed with snow. August was a very cold, wet month; there were a few warm days, during which no rain fell, and there

were a few fine dry days in the early part of September, after which rain fell almost daily until the end of the month.

TABLE XVI.—SUMMARY of the RESULTS of the THIRTY-SIXTH SEASON, 1878–79.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	4 2¾	52·5	330	763
2	14 tons farmyard-manure	16 0	56·8	1064	2239
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	3 3¾	48·9	272	889
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	4 2¼	49·8	345	1070
5A & B	Mixed mineral manure alone	5 2¾	53·5	384	855
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	10 2	56·5	691	1592
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	16 1	56·7	1051	3012
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	21 3¾	56·5	1462	4347
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	20 2¼	56·5	1351	4176
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	15 2	61·0	..	..

We have already written so fully upon the crop of 1879 in the Journal of this Society, vol. xvi. part i. 1880, that it will be sufficient to say here, that it was not only by far the worst crop grown during the forty years of our experiments, but it was certainly the worst grown in Great Britain since the year 1816. It will be enough to give one instance. On plot 7 the yield in 1863 was 53½ bushels per acre, while the same manure in 1879 was only competent to produce 16¼ bushels! It was estimated that the crop of the country was not much more than half an average one.

Thirty-seventh Season, 1879–80.

October was both cold and sunless, but at the same time exceedingly dry. November and December were also both cold and dry; there is, in fact, no record of so cold a December since the beginning of the century. January was exceedingly cold and dry, hardly any rain falling from the beginning to the end of the month. February was warm, with a rainfall over the average. March was warm during the first half of the month, and afterwards cold, but very dry. April was alternately cold and warm, the latter predominating; the rainfall was slightly

over an average, which, following so dry a March, was very beneficial. May was cold and dry, the nights being very cold, and vegetation was backward. June was very cold and unsettled during the first half of the month; afterwards the weather became warmer, and from the 19th to the 26th thunderstorms were frequent, with heavy rain and hail which greatly damaged the crop.

July was dull, unsettled, and wet. Thunderstorms were frequent from the 14th to the 16th. The fall of rain was in some places over 3 inches; while in others hailstorms occurred, which did considerable injury to the crops. Up to August 8th the weather was cold and wet, but after this date it was fine to the end of the month. The first week in September was very fine and hot, but during the rest of the month there was a great deal of wet.

TABLE XVII.—SUMMARY of the RESULTS of the THIRTY-SEVENTH SEASON, 1879–80.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.				
		Dressed Corn.			Total Corn.	Straw and Chaff.
		Quantity.		Weight per Bushel.		
		bush.	pks.	lbs.	lbs.	lbs.
3	Unmanured	11	2	56·9	689	1149
2	14 tons farmyard-manure	38	1½	60·2	2373	3902
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	10	2½	54·9	645	1242
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	10	1¾	53·5	654	1420
5A & B	Mixed mineral manure alone	17	2¾	59·2	1083	1735
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	26	3¾	59·8	1664	2911
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	34	2	59·8	2149	4006
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	34	0½	57·8	2130	4394
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	35	1½	59·1	2203	4476
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	30	0	61·0	..	..

The wheat crop of 1880 gave a higher produce—38 bushels per acre—on the plot which receives farmyard-manure than was obtained upon any of the artificially manured plots. The large store of latent fertility in the dunged plot—which may become active whenever the season is favourable—makes the yield of wheat on this plot subject to fluctuations of a different character from those of the other manured plots. The estimated yield of the crop of the country was rather above the average.

Thirty-eighth Season, 1880–81.

October was excessively cold and wet. On the 20th there was a heavy snowstorm, which was however much heavier in the south of England than elsewhere. The wheat was got in with great difficulty, and much land was left unsown. November was alternately cold and warm, and rain fell every day from the 8th to the 26th. December was a mild month, and the first half was dry, after which the rain was continuous until the end of the year.

The first few days in January were fine, after which very bad weather set in and snow fell on every day except one from the 9th to the 27th. February was a wet, cold, and gloomy month with frequent falls of snow. March was cold at the beginning and at the end of the month, but warm between the 4th and the 20th. The rainfall of the month was slightly below the average. The quarter was remarkable for the great falls of snow. April was a very dry month; cold at the beginning, warm from the 10th to the 18th, and moderately cold afterwards. May was generally cold, and on the 10th and 11th a very severe frost occurred, causing great damage to the crops. The weather was afterwards variable but on the whole cold. June was alternately cold and hot, the temperature of the month being about equal to the average, while the rainfall was slightly below the average.

TABLE XVIII.—SUMMARY of the RESULTS of the THIRTY-EIGHTH SEASON, 1880–81.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	13 3	58·0	863	1146
2	14 tons farmyard-manure	30 0¾	58·9	1907	2367
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	18 0¾	58·4	1168	1297
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	22 3	58·5	1424	1817
5A & B	Mixed mineral manure alone	12 2¾	57·9	806	903
6A & B	Mixed mineral manure, and 200 lbs. ammonium-salts = 43 lbs. N.	21 2¾	57·8	1358	1629
7A & B	Mixed mineral manure, and 400 lbs. ammonium-salts = 86 lbs. N.	26 2¾	58·8	1714	2203
9A	Mixed mineral manure, and 550 lbs. nitrate of soda = 86 lbs. N.	35 1¾	58·4	2271	3640
8A & B	Mixed mineral manure, and 600 lbs. ammonium salts = 129 lbs. N.	30 2¾	59·1	1962	2906
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	24 0	61·0	..	..

July was a month remarkable for the variations of temperature in Great Britain; in some districts the temperature exceeded 90, and for days together 80, while in others the month was cold, cloudy, and wet. In the wheat-districts it may be said to have been a very hot and dry month. The first week in August was fine and dry, after which the weather to the end of the month was cold with almost constant rains, which did considerable injury to the wheat. The crop of the country was several bushels below the average.

Thirty-ninth Season, 1881–82.

October was excessively cold, with violent gales, and rainfall slightly below the average. November was exceedingly warm, with rainfall also slightly below the average. December was alternately warm and cold, the temperature and the rainfall being about the average.

January was excessively warm and dry, spring flowers being in bloom. February and March were also both warm and dry, and vegetation was very forward; indeed, from November to the end of March the weather may be described as being most favourable for the crops. April was generally warm until towards the end of the month, with more than an average rain-

TABLE XIX.—SUMMARY of the RESULTS of the THIRTY-NINTH SEASON, 1881–82.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	10 3¾	58·7	679	1095
2	14 tons farmyard-manure	32 2¾	59·6	2004	3993
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	23 2¾	60·7	1557	2796
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	24 1¼	58·0	1520	3617
5A & B	Mixed mineral manure alone	12 2	58·5	777	1281
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	23 0½	60·8	1467	2919
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	35 3½	60·0	2251	5730
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	31 3½	59·8	2012	6274
8A & B	Mixed mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	37 0	59·1	2323	7110
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	25 2½	61·0	..	..

fall. May—except during one week at the commencement—was a warm and growing month, and the rainfall was less than the average. June was cold and unseasonable throughout, with an excess of rain which seriously damaged the luxuriant crop of hay. July was cold, wet, and ungenial, and this weather, following upon a cold and wet June, seriously interfered with the ripening of the corn. The beginning of August was fine, followed by cold and showery weather on the 14th; the rainfall was, however, low.

The produce of this crop, on the whole, does not differ much from that of 1881. It may be observed, however, that while the yield of the nitrate of soda plots was not widely different in the two years, the salts of ammonia gave very much more produce in the present year.

Fortieth Season, 1882–83.

The first half of October was warm, the second half cold, and the whole month was excessively wet. In consequence, the wheat was got in very badly. November was alternately warm and cold, with an average rainfall. The land was very wet all the month. The first half of December was very cold, the second half was warm, snow fell frequently, and the rainfall was over the average. January was warm throughout, with a great deal of rain and heavy storms from the 24th to the 28th. February was mild throughout the month, with excessive wet during the first three weeks. After March 6th the temperature was very cold and dry, and what little moisture fell was in the form of snow. The beginning of April was warm, but from the 9th to the 25th the weather was cold, snow falling on several days. Both March and April were favourable for farming operations.

The first twelve days of May were cold, after which the weather was fine and warm until the end of the month. June was an unsettled month, being first warm, then cold and warm alternately. It was very cold from the 15th to the 22nd, and unsettled to the end of the month. The rainfall was below the average. July was fine and warm until the 10th, the remainder of the month was cold and unsettled, with rain a little above the average. August was cold at the beginning, and warm generally afterwards, with a good deal of bright summer weather and but little rain. September, which is usually a good harvest month, was generally favourable except in the north.

Although the yield of this crop, both on the unmanured, and on the variously manured plots was considerably over an

average, it was not considered that more than an average crop was grown throughout the country.

TABLE XX.—SUMMARY of the RESULTS of the FORTIETH SEASON, 1882–83.

Plots.	Manures. (Quantities per Acre.)	Produce per Acre, &c.			
		Dressed Corn.		Total Corn.	Straw and Chaff.
		Quantity.	Weight per Bushel.		
		bush. pks.	lbs.	lbs.	lbs.
3	Unmanured	13 3½	61·2	872	1006
2	14 tons farmyard-manure	35 0½	62·4	2244	2930
10A	400 lbs. ammonium-salts alone = 86 lbs. N.	17 2	60·4	1196	1419
9B	550 lbs. nitrate of soda alone = 86 lbs. N.	19 0½	59·6	1337	1684
5A & B	Mixed mineral manure alone	15 2¾	61·9	1009	1138
6A & B	Mixed mineral manure, and .. .. .. 200 lbs. ammonium-salts = 43 lbs. N. ..	27 2½	62·8	1781	2605
7A & B	Mixed mineral manure, and .. .. .. 400 lbs. ammonium-salts = 86 lbs. N. ..	36 0½	62·9	2378	3632
9A	Mixed mineral manure, and .. .. .. 550 lbs. nitrate of soda = 86 lbs. N. ..	43 1½	62·1	2905	5127
8A & B	Mixed mineral mineral manure, and .. .. .. 600 lbs. ammonium-salts = 129 lbs. N. ..	41 8¼	63·5	2783	4291
	Estimated average for the United Kingdom reckoned at 61 lbs. per bushel	28 0	61·0	..	..

Best and Worst Seasons.

Every one engaged in farming knows that the growth of his crops is dependent upon the weather; still, the treatment of land in common practice is not so uniform as to enable any one to measure the influence of climate upon any particular crop. To do this the crop must be grown continuously upon the same land, and no change must be made in the manures applied.

During the period of forty years that has elapsed since the commencement of the continuous wheat crop, it is probable that we have experienced fluctuations of season as great as are likely to occur in any similar period. In the following table (p. 38) will be found the produce of selected plots, in the year of the greatest produce, 1863, and in that of the worst produce in 1879, together with the average produce of the period of thirty-two years.

The reason for giving the average of the last 32 years, instead of that of the whole period of 40 years, is that in the early years of the experiments some changes in the manures applied took place on certain plots, while for the last 32 years, the same manures have been used almost without change.

TABLE XXI.—Showing the PRODUCE of the BEST SEASON, 1863, the WORST SEASON, 1879, and the AVERAGE of 32 YEARS, 1852–1883.

Plot Nos.	Description of Manures. Quantities per Acre.	Best Season, 1863.	Worst Season, 1879.	Difference.	Average 32 Years, 1852–'83.
	DRESSED GRAIN, PER ACRE—BUSHELS.				
3	Unmanured	17¼	4⅜	12⅞	13⅛
2	Farmyard-manure	44	16	28	33⅜
5	Mixed mineral manure alone	19⅜	5⅜	14	15½
6	Mix. min. man. & 200 lbs. am.-salts = 43 lbs. N.	39⅜	10½	29⅛	24¼
7	Mix. min. man. & 400 lbs. am.-salts = 86 lbs. N.	53⅜	16¼	37⅛	32¾
9	Mix. min. man. & 550 lbs. nitr.-soda = 86 lbs. N.	55⅝	22	33⅝	36¼
8	Mix. min. man. & 600 lbs. am.-salts = 129 lbs. N.	55¾	20⅝	35⅛	36¼
	WEIGHT PER BUSHEL OF DRESSED GRAIN—LBS.				
3	Unmanured	62·7	52·5	10·2	58·8
2	Farmyard-manure	63·1	56·8	6·3	60·0
5	Mixed mineral manure alone	63·0	53·5	9·5	58·7
6	Mix. min. man. & 200 lbs. am.-salts = 43 lbs. N.	62·3	56·5	5·8	59·5
7	Mix. min. man. & 400 lbs. am.-salts = 86 lbs. N.	62·5	56·7	5·8	59·5
9	Mix. min. man. & 550 lbs. nitr.-soda = 86 lbs. N.	62·1	56·5	5·6	58·7
8	Mix. min. man. & 600 lbs. am.-salts = 129 lbs. N.	62·3	56·5	5·8	59·2
	STRAW (AND CHAFF) PER ACRE—LBS.				
3	Unmanured	1600	763	837	1272
2	Farmyard-manure	4279	2239	2040	3570
5	Mixed mineral manure alone	1728	855	873	1464
6	Mix. min. man. & 200 lbs. am.-salts = 43 lbs. N.	3715	1592	2123	2512
7	Mix. min. man. & 400 lbs. am.-salts = 86 lbs. N.	5866	3012	2854	3771
9	Mix. min. man. & 550 lbs. nitr.-soda = 86 lbs. N.	6312	4347	1965	4688
8	Mix. min. man. & 600 lbs. am.-salts = 129 lbs. N.	6602	4176	2426	4532
	TOTAL PRODUCE (GRAIN AND STRAW) PER ACRE—LBS.				
3	Unmanured	2,727	1093	1634	2090
2	Farmyard-manure	7,165	3303	3862	5689
5	Mixed mineral manure alone	3,017	1238	1779	2421
6	Mix. min. man. & 200 lbs. am.-salts = 43 lbs. N.	6,243	2283	3960	4029
7	Mix. min. man. & 400 lbs. am.-salts = 86 lbs. N.	9,358	4063	5295	5845
9	Mix. min. man. & 550 lbs. nitr.-soda = 86 lbs. N.	9,888	5809	4079	6982
8	Mix. min. man. & 600 lbs. am.-salts = 129 lbs. N.	10,216	5527	4689	6832

In the year 1863, the produce of the unmanured land was 17¼ bushels; and in the worst year, 1879, it was 4¾ bushels. As previous to the year 1863, 19 unmanured crops had been already taken, the produce obtained was not the largest which had been grown; and it is quite probable that had the season of 1863 occurred at the beginning of the period, the yield would have been considerably over 20 bushels. As it was, the yield of 1863 was equal to the average of the first 8 years.

In 1879 the yield without manure was, as we have mentioned, only 4¾ bushels per acre, with a weight of 52½ lbs. per bushel, or about one-third of the average produce of the plot during the whole period of 40 years.

The produce of the land receiving 14 tons of dung every year was, in 1863, 44 bushels, and in 1879, 16 bushels per acre; a difference of 28 bushels per acre between the best and worst seasons.

Contrary to what might be expected, the produce on the land receiving dung, while it falls greatly in yield in a bad season, does not rise as rapidly in yield in a very favourable season. This will be seen more clearly by a comparison with the land which receives artificial manures. We find that plot 7, receiving mineral manures and salts of ammonia, gave in 1879 a crop exactly the same as that of the dung—16 bushels per acre; and we also find that the average produce of the 32 years is almost identical in both cases, one being 32¾ bushels, and the other 33 bushels per acre. But in the favourable season of 1863, we find that while the dung gave only 44 bushels per acre, the artificial manures gave a produce of 53⅝, an excess of nearly 10 bushels per acre.

It is evident, therefore, that, under the most favourable climatic circumstances, the artificial manure is competent to give a much larger crop, both of corn and straw, than the dung.

In the same year (1863), plot 9, which received an equivalent amount of nitrogen in the form of nitrate of soda to that supplied in the salts of ammonia on plot 7, gave a slightly higher produce, the yield amounting to 55½ bushels per acre; and of total produce (corn and straw), this plot gave considerably more than one ton per acre in excess of the yield on the dunged plot.

To sum up, we find that with the heaviest artificial manuring (plot 8), 35⅛ more bushels per acre of wheat, and more than 2 tons per acre more gross produce (corn and straw), were grown in the most favourable season, as compared with the produce grown by the same manures in the worst season.

The Permanently Unmanured Plot.

The last time this land received any manure was in 1839. The crop, which was then turnips, was followed by barley,

peas, wheat, and oats, the last four crops being grown without any manure whatever. In the event of a failure of the clover-crop, such a course would not at that period have been unusual in the district, although in those days a top-dressing of soot would, in all probability, have been applied to the wheat. In this case, however, it was not applied; and, even if it had been applied, the land after the oat-crop would be considered, agriculturally speaking, to be exhausted.

It was at this period that the Rothamsted experiments were commenced, for the purpose of ascertaining what amount of crop the land would yield in wheat, without the aid of manure. The cultivation has been throughout of the most simple description, and no attempt has been made to increase the crop by deep, or subsoil ploughing. The land has, however, been kept free from weeds.

In the following table will be found a summary of the results, given in 4 periods of 10 years each:—

TABLE XXII.—Showing the AVERAGE NUMBER of BUSHELS of DRESSED CORN per ACRE, the WEIGHT per BUSHEL, and the TOTAL PRODUCE (CORN and STRAW), per ACRE, of the PERMANENTLY UNMANURED LAND, over FOUR PERIODS of TEN YEARS each.

	Bushels of Dressed Corn per Acre.	Weight per Bushel, lbs.	Total Produce (Corn and Straw) in lbs.
Mean of 10 years, 1844–1853	15¾	58·25	2711
Mean of 10 years, 1854–1863	16½	57·57	2728
Mean of 10 years, 1864–1873	12¾	58·97	1924
Mean of 10 years, 1874–1883	10½	58·25	1614
Mean of 40 years	14	58·26	2244

We have already noticed the number of fine wheat seasons which occurred during the second 10 years of the experiments, and we may further mention that the effect of these favourable seasons was sufficient to make the yield of grain of the second 10 years of unmanured wheat slightly higher than that of the first period, the average of the dressed corn per acre in the first period being 15¾, and in the second period 16½ bushels per acre. The total produce (corn and straw), which is a much more accurate measure of the available fertility of a soil than the grain alone, is also slightly higher over the second period, with its more favourable seasons, than over the first.

In the third period of 10 years, the average decline is very decided, the average produce for the 10 years being less than 13 bushels per acre, or nearly 4 bushels below the produce of the

previous 10 years. In the fourth period of 10 years, the average produce was only 10¼ bushels per acre.

It is well known to all those connected with the land in Great Britain that the seasons have latterly been most unfavourable for the growth of wheat. It is therefore evident that the produce of the last 10 years does not correctly represent the reduction due to exhaustion of the soil alone. This, indeed, is proved by the fact that, under the influence of a rather better season, the produce of the last year, 1883, was 13¾ bushels per acre, which very nearly represents the average yield of the 40 crops.

In our paper on "Home Produce, Imports, and Consumption," we made some attempts to calculate what was the annual decline in the produce due to exhaustion—irrespective of variations due to good or bad seasons—and it would appear probable that, up to a certain period, the decline might amount to about ¼ of a bushel per acre per annum—equal to a gross produce in corn and straw of 40 lbs. per acre.

It is evident, however, that with each decline the reduction will become less and less. Atmospheric influences, and even the small amount of ammonia brought down in the rain, will form a larger factor upon a declining crop. It is evident, therefore, that the actual process of the exhaustion of the soil differs considerably from all the preconceived ideas upon the subject. The soil, in fact, not only contains more fertility, but also holds it with a much firmer grasp, and parts with it less readily than we had previously imagined.

The average amount of total produce (corn and straw) removed has been 1 ton per acre, containing nearly 1900 lbs. of absolutely dry matter; and we have very strong evidence, derived from other experiments in the field, to prove that the carbon, indeed a large proportion of the organic matter, is derived from the atmosphere, while the nitrogen and the mineral matters are taken from the soil. This would divide the products into from 94 to 95 per cent. atmospheric constituents (including water), and from 5 to 6 per cent. soil constituents.

The average amount of soil constituents (minerals and nitrogen) annually removed by this unmanured wheat crop is from 100 lbs. to 120 lbs. per acre; and of the three most important constituents of plant growth there have been removed about 17 lbs. of potash, 10 lbs. of phosphoric acid, and 20 lbs. of nitrogen.

Such are the results obtained up to the present time, and they may be summed up as follows:—Upon a field which has been under arable cultivation certainly for two or three centuries—and possibly for a much longer period—and which has consequently lost a very considerable amount of its

original fertility, we find—after the removal of 40 unmanured crops—a yield which differs very little from the average of some of the great wheat-growing countries of the world: the yield of the United States, India, and China being, it is stated, from 12 to 13 bushels per acre.

Now the Rothamsted soil certainly contains a very much less stock of fertility than the soils upon which wheat is extensively grown in other countries. It is therefore impossible to attribute the comparatively large yield in our experimental crops to any other cause than to the clean state of the land. The amount of food at the disposal of the plant is small, but it is not shared to any great extent with other plants.

By way of illustration of what may occur where the land is not kept clean, we may mention that last autumn a portion of the crop at the top of our wheat field was left standing and allowed to shed its seeds, the soil not being disturbed in any way. About 14 bushels per acre fell upon the land, and up to a certain period the self-sown wheat was fairly plentiful. By this time, however,—less than one year—the weeds have almost destroyed the crop; and if the seed is left to sow itself again, it is very probable that every plant will be driven out before next summer.

The large produce of both wheat and barley on the unmanured land in the Woburn experiments, also shows how much the crops grown upon the ordinary cultivated land of the country are reduced by weeds. It is true that weeds do not exhaust a soil, as, in their decay, the fertility which they have taken up becomes again available; but they take up nitric acid, which, during their growth, reverts to the form of organic nitrogen.

When this occurs in regard to the soil-nitrogen, it is merely so much nitric acid employed in growing weeds instead of wheat; but when active nitrogen, as in salts of ammonia, or nitrate of soda, has been applied to the land, the loss is much more serious. A high price is paid for these substances, in consequence of the nitrogen they contain being in a very active form, competent to produce crop growth; whereas if weed growth takes place instead, the purchased nitrogen does not become available as food for the crop until the weeds decay.

Mineral Manures without Ammonia.

In our previous paper on the Growth of Wheat we were only able to give the produce of this plot for 12 years, as during the first 8 years of the experiment manures containing ammonia had been used in considerable quantities. We are now able to give the produce of this plot for 32 years, during which period a liberal supply of all the necessary mineral food of the wheat

crop has been placed upon the land every year, while for its nitrogen the crop has been left dependent upon the supplies furnished by the soil and atmosphere.

In the following table will be seen the produce of this plot for 4 periods of 8 years each, and for the total period of 32 years: and, for comparison, there is also given the produce of the permanently unmanured plot over the same periods.

TABLE XXII.—Showing the AVERAGE PRODUCE of DRESSED CORN, and TOTAL PRODUCE (CORN and STRAW), per acre, on PLOT 3 (the PERMANENTLY UNMANURED PLOT), and PLOT 5, which has received MIXED MINERALS for a period of 32 YEARS, over 4 periods of 8 YEARS each, and over the total period.

	Dressed Corn.		Total Produce (Corn and Straw).	
	Without Manure, Plot 3.	Mixed Minerals, Plot 5	Without Manure, Plot 3.	Mixed Minerals, Plot 5.
	bushels.	bushels.	lbs.	lbs.
8 years, 1852–1859	16⅛	19	2736	3191
8 years, 1860–1867	13⅜	15¼	2183	2450
8 years, 1868–1875	12¼	14	1833	2144
8 years, 1876–1883	10⅜	12⅜	1610	1899
32 years, 1852–1883	13⅛	15½	2090	2421
40 years, 1844–1883	14	..	2244	..

During the first 8 years of the experiments (1844–1851), plot 5 received salts of ammonia, as well as mineral manures, and the average produce of wheat during those 8 seasons was 29 bushels per acre, or nearly 12 bushels annually in excess of the produce on the unmanured plot; while during the first 8 years of the mixed minerals, without the salts of ammonia (1852–1859), the average produce was 19 bushels per acre, or about 3 bushels more than the permanently unmanured produce.

In the second period of 8 years for which the results are given in the table, the produce of the mixed minerals' plot amounted to 15¼ bushels per acre, as against 13⅜ bushels grown on the unmanured plot, a difference of 1¾ bushels in favour of the mixed minerals' plot. In the third period of 8 years, the produce of plot 5 was 14 bushels per acre: and in the last period of 8 years, it was 12⅜, or rather more than 12½ bushels per acre.

The whole period of 32 years has thus given an average of 15½ bushels on the mixed minerals' plot, as against 13⅛ bushels on the permanently unmanured plot; and if we take the average produce of the unmanured plot for 40 years, the yield has been 14 bushels per acre. The application, therefore, of a

very liberal supply of minerals has only been competent to increase the yield by 1¼ bushels per acre per annum!

The average total produce—corn and straw—of the mixed minerals' plot for the 32 years, amounted to 2421 lbs., and that of the unmanured plot to 2090 lbs., a difference of 331 lbs. in favour of the minerals. The amount of nitrogen in this 331 lbs. would be not more than 3 lbs. This represents the whole of the nitrogen which the wheat upon an acre of land, though furnished with an abundance of minerals, and certainly at the commencement containing more crop residue than the unmanured land, has been able to obtain from the soil and atmosphere in excess of that in the wheat grown without manure!

In order to explain the causes which have produced these crops, it will be necessary to show what has taken place in the soil; but before doing so, it may be as well to give a slight review of the crops themselves.

We find the two crops running a parallel course, showing great differences in their yield as the seasons are favourable or unfavourable, but rarely differing from each other more than from 3 to 4 bushels per acre. The yield in both is slowly declining, as we find that during the first 8 years the unmanured produce gave, in two separate years, a crop of 20 bushels per acre; and the mineral-manured plot on three occasions yielded a crop exceeding 20 bushels per acre. For the last 24 years, neither plot has given a produce of 20 bushels, and it is hardly possible that, without some change in the manures applied, a crop of this amount can ever be grown again.

The Rothamsted soil—like a great many cultivated soils—contains a large amount of the mineral food of plants; it also contains organic nitrogen, that is to say, nitrogen in combination with carbon, the residue of previous vegetation. This organic nitrogen does not appear to be available as food for the wheat plant, but every year a certain amount of it is converted into nitric acid, which combines with the lime in the soil. In this state it is very soluble in water, is readily washed out of the soil by heavy rain, and, further, is a most important and essential food of the wheat plant.

The amount of nitric acid formed each year will vary, the formation being most rapid in the hottest weather, provided the soil is sufficiently moist. The amount of nitric acid which the wheat crop can take up will also vary, and in a cold and wet winter much will be washed beyond the reach of the roots of the plant.

These facts, which are of universal application, enable us to explain some of the causes which tend to the production of good or bad crops of wheat. Analyses of the soil of these two

plots, made at different times, show that both have lost a large amount of organic nitrogen; and that, in the first 9 inches from the surface, the mineral-manured soil has lost rather the most.

The total loss of nitrogen over a given area is larger than the amount of that substance removed in the crops, and the reason for this will be found in an examination of the drainage-water. Except when the crop is in full vigour of growth, the drainage-water contains nitric acid. In our paper on Rain and Drainage, published in this Journal, we have gone so fully into this question that it will be sufficient here to say that of the 28 lbs. to 32 lbs. of nitrogen available per acre each year, from soil, seed, rain, &c., we estimated that only about $\frac{2}{3}$ are removed in the crop, and that $\frac{1}{3}$ goes into the drains and is lost.

There was rather more nitric acid formed in the soil which received minerals, and in consequence the crop was slightly increased; but the evidence is distinct and conclusive as regards the very small effect which followed the large applications of mineral matter.

On the unmanured soil the minerals at the disposal of the crop were quite sufficient to utilise the whole of the nitric acid available; in fact the results obtained on plot 10 A show that the available minerals were competent to grow a much larger crop than that actually produced on the unmanured plot. Further, as very little more nitric acid was liberated on the mineral plot — and the crop was unable to obtain nitrogen from the atmosphere—we have a produce very slightly in excess of that grown on the permanently unmanured land.

By means of these experiments we more readily arrive at an explanation of the fact that on some soils—more especially the newly cultivated soils of the United States—a large increase in the wheat crop frequently follows the application of mineral manures. Soils rich in organic matter may yield an increased amount of nitric acid by the application of phosphates and potash, but in all cases the source of the nitrogen is the soil; and the loss by the unmanured soil of perhaps from 800 to 1000 lbs. of nitrogen per acre during the 40 years of these experiments is a fact of the greatest importance.

Ammonia without Minerals, and Ammonia in alternation with Minerals.

Plots 10 A and 10 B, and Plots 17 and 18.

The recent legislative enactments, giving the cultivator of the soil a claim for the manure ingredients possessing a pecuniary value, which he has applied, and left in the land, add greatly to the interest of all investigations which have a bearing upon this important subject.

In plots 10 A and 10 B, we have two parallel experiments. In 1844 both received an application of mineral manures, and produced a crop yielding 15½ bushels of grain per acre. In 1845, both received a dressing of salts of ammonia, which yielded a crop of 32 bushels per acre.

From that time they have been treated as two separate experiments; 10 A, from 1846 to the present time—a period of 38 years—has received annually a dressing of salts of ammonia: while in 1846, 10 B was unmanured. In 1848, 10 B received a dressing of minerals, and the same amount of salts of ammonia as 10 A. In 1849, it received salts of ammonia alone, and in 1850, minerals alone.

The difference between the two plots has therefore been as follows: 10 A has received one dressing of minerals, followed by 39 dressings of salts of ammonia: 10 B has received three dressings of minerals during the first 7 years; and for the last 33 years both plots have been manured exactly alike, receiving salts of ammonia every year.

In the following table will be seen (1) the produce of each plot in each of the first 8 years: (2) the average produce over succeeding periods of 8 years each: (3) the average produce over 32 years, 1852–1883.

TABLE XXIV.—Showing the PRODUCE of 10 A and 10 B, for each of the FIRST 8 YEARS of the EXPERIMENT, and afterwards the AVERAGE PRODUCE over PERIODS of 8 YEARS. 10 A received MINERAL MANURE alone in 1844, and SALTS of AMMONIA alone in each of the last 39 YEARS. 10 B received MINERALS alone in 1844 and 1850, was unmanured in 1846, received MINERALS with SALTS of AMMONIA in 1848, and SALTS of AMMONIA alone (the same as 10 A) in 1845, 1847, 1849, 1851, and in each of the last 32 YEARS.

	Dressed Corn.		Total Produce (Corn and Straw).	
	Plot 10A.	Plot 10B.	Plot 10A.	Plot 10B.
	bushels.	bushels.	lbs.	lbs.
1844	15½	15½	2120	2120
1845	31⅞	31⅞	6246	6246
1846	27⅜	17⅜	4094	2671
1847	25¾	25¾	4593	4579
1848	19¼	25¼	3701	4530
1849	32⅜	32⅜	4992	5117
1850	27	18	4810	3120
1851	28⅞	28⅝	5036	4985
8 years, 1852–1859	22¾	27½	4055	4885
8 years, 1860–1867	24	27½	4076	4563
8 years, 1868–1875	19	20½	3060	3264
8 years, 1876–1883	16⅜	18⅛	2618	2935
32 years, 1852–1883	20½	23¼	3452	3912

It will be observed that in 1848, when 10 B received mineral manures as well as salts of ammonia, the produce was 25⅛ bushels per acre, as against 19¼ bushels per acre on plot 10 A, which received the same salts of ammonia without minerals. On the other hand, when 10 B, in 1850, received minerals alone, the produce was only 18 bushels per acre as against 27 bushels obtained on 10 A, which was manured with salts of ammonia only.

Turning now to the periods of 8 years each, it will be seen that in every case the produce of 10 B was larger than that of 10 A; the difference is however a declining one, being in the first 8 years not quite 5 bushels per acre per annum, in the last 8 years 1¾ bushels per acre, and over the whole period not quite 3 bushels per acre per annum.

It is well known that the drainage-water that comes from cultivated fields contains but a very small amount of potash, and frequently no phosphoric acid; we have no difficulty, therefore, in tracing the increased produce obtained on 10 B over 10 A to the minerals applied to the former in 1848 and 1850.

The amounts of potash and phosphoric acid applied to 10 A and 10 B have been exceeded by those removed in the crops many years ago; but the much greater amounts which 10 B received in the earlier years of the experiment have caused the resources of the soil to be much more largely drawn upon by the crops on plot 10 A, than by those on plot 10 B.

These large applications of potash and phosphoric acid—although applied in the form of soluble compounds—appear to enter into very fixed combinations, somewhat similar to those already existing in the soil; and in this respect they differ altogether from compounds of ammonia and nitric acid, as the latter appear to be either washed away or destroyed, unless they are fixed by vegetation, while the former are fixed by the soil itself, and are only taken out of it by means of vegetation.

Plots 17 and 18.

In the last experiment it was shown that potash and phosphoric acid were producing an influence upon the wheat crop 33 years after their application.

In the experiment to which we are now about to refer we have to trace the unexhausted residue of another substance perfectly soluble in water. On plots 17 and 18 the mineral manures and the salts of ammonia are never used together. When plot 17 receives minerals, plot 18 receives salts of ammonia; and when plot 18 receives minerals, plot 17 receives salts of ammonia. During the 32 years of the experiments each plot

has received 16 applications of mineral manures, and 16 applications of salts of ammonia.

It is evident that an experiment of this description is well adapted to ascertain the unexhausted residue of a manure like salts of ammonia. For the crops of the first 8 years (1844–1851) the two plots received different artificial manures, yielding a very similar produce. In the following table will be found the average produce of the mineral manures, and also of the salts of ammonia, over periods of 8 years each, from 1852 to 1883; further, for comparison, is given the average produce of plot 5, where minerals alone have been employed.

TABLE XXV.—Showing the BUSHELS of DRESSED CORN, and TOTAL PRODUCE (CORN and STRAW), on PLOTS 5, 17, and 18; 5 being MANURED with MIXED MINERAL MANURES alone during the whole PERIOD, and 17 and 18 receiving alternately MINERALS and SALTS of AMMONIA.

	Dressed Corn, per Acre.			Total Produce (Corn and Straw), per Acre.		
	Mineral Manures only, every Year. Plot 5.	Mineral Manures. Plots 17 or 18.	Salts of Ammonia. Plots 17 or 18.	Mineral Manures only, every Year. Plot 5.	Mineral Manures. Plots 17 or 18.	Salts of Ammonia. Plots 17 or 18.
	Bushels.	Bushels.	Bushels.	lbs.	lbs.	lbs.
8 years, 1852–1859 ..	19	18⅞	32⅜	3191	3235	5938
8 years, 1860–1867 ..	15¼	16½	31½	2450	2696	5297
8 years, 1868–1875 ..	14	15	28½	2144	2404	4781
8 years, 1876–1883 ..	12⅜	12¼	27⅜	1899	1869	4930
32 years, 1852–1883 ..	15¼	15⅝	30	2421	2551	5237

Looking at the bottom line—which gives the average of the whole period of 32 years—it will be seen that during the 16 alternate seasons in which plot 17 received salts of ammonia, and the 16 alternate seasons in which plot 18 received that substance, the average produce was 30 bushels per acre; while during the alternate years, in which the plots received minerals only, they yielded only 15⅝ bushels; or in other words, only a fraction of a bushel more than plot 5, which received no ammonia during the whole period!

In the 400 lbs. of salts of ammonia it is estimated that 86 lbs. of nitrogen are applied to an acre.

The resources of the soil were evidently competent to furnish the nitrogen contained in 15 bushels of wheat, and its straw, as we obtained that produce on plot 5 which receives no ammonia. In the remaining 15 bushels and its straw, obtained by the

application of the salts of ammonia, certainly less than 26 lbs. of nitrogen have been carried off, thus leaving 60 lbs. of nitrogen to be accounted for!

In the autumn of 1881, the soil of the various experimental plots was sampled and analysed, both for the total nitrogen and for nitric acid, to the depth of 27 inches. Although the soil of plots 17 and 18 contained rather more total nitrogen and nitrates than plot 5, still—within the range examined—there was no evidence of the existence in the soil of the large amount of nitrogen supplied in the manure, and not accounted for in the crop.

It is quite certain, therefore, that when salts of ammonia are applied to grow wheat, it is not safe to calculate upon any of the unexhausted residue being available for the purpose of growing a second corn-crop.

There is also evidence to show that the exhausting character which practical farmers attribute to corn crops, is quite as much due to the nitrogen which they do not assimilate being washed out of the soil, as it is to the amount of that substance which is removed in the produce.

Mixed Minerals with Salts of Ammonia, and Nitrate of Soda.

Having already given the results of experiments in which mixed minerals were used alone, as also where salts of ammonia were used alone, we now come to another series of experiments, where one uniform quantity of mixed minerals was used in each case, but with different amounts of nitrogen in the form of salts of ammonia, and also as nitrate of soda. The applications were as follows:—Plot 6 A and B received 200 lbs. of sulphate and muriate of ammonia, containing 43 lbs. of nitrogen; plot 7 A and B, 400 lbs. of the same salts, containing 86 lbs. of nitrogen; and plot 8 A and B, 600 lbs. of the same salts, containing 129 lbs. of nitrogen; while plot 9 A, received 86 lbs. of nitrogen as nitrate of soda, instead of as salts of ammonia.

For the thirteen years, 1852–1864, we further employed on plot 16 A and B, 800 lbs. of salts of ammonia, containing 172 lbs. of nitrogen; but even in 1863 — a season which for productiveness is not likely to be repeated except at rare intervals—the 800 lbs. produced so small an increase over the manure containing 600 lbs. of salts of ammonia, that it was decided to stop the application, with the view of obtaining, by this means, some information in regard to the unexhausted residue of manures.

In the following table is given—for 4 periods of 8 years each—the produce of wheat grown by the minerals and nitrogen in

various proportions for 32 years in succession; and for comparison the produce over the same periods, obtained by the mineral manure alone.

TABLE XXVI.—Showing the AVERAGE PRODUCE of DRESSED CORN, in BUSHELS, and TOTAL PRODUCE (CORN and STRAW), in LBS., per ACRE, grown by MIXED MINERALS alone, by MIXED MINERALS with SALTS of AMMONIA in various proportions, and by MIXED MINERALS with NITRATE of SODA, over periods of 8 YEARS, and over 32 YEARS.

	Mixed Minerals alone.	With Salts of Ammonia.			With Nitrate of Soda.
		= 43 lbs. Nitrogen.	= 86 lbs. Nitrogen.	= 129 lbs. Nitrogen.	= 86 lbs. Nitrogen.
DRESSED CORN PER ACRE IN BUSHELS.					
8 years, 1852–1859	19	27⅞	35½	36⅞	31⅛
8 years, 1860–1867	15¼	26¼	36¼	39⅝	40¼
8 years, 1868–1875	14	22	31	36	39
8 years, 1876–1883	12⅝	20⅜	28	32¼	34⅝
32 years, 1852–1883	15¼	24⅛	32⅝	36¼	36¼
TOTAL PRODUCE (CORN AND STRAW), PER ACRE, LBS.					
8 years, 1852–1859	3191	4808	6490	7012	5897
8 years, 1860–1867	2450	4276	6262	7363	7862
8 years, 1868–1875	2144	3612	5379	6593	7344
8 years, 1876–1883	1899	3422	5248	6361	6824
32 years, 1852–1883	2421	4029	5845	6832	6982

Taking the three proportions of nitrogen, as applied in salts of ammonia, it will be seen that in the separate periods of 8 years each, and also in the whole period of 32 years, the increase of wheat obtained by the addition of 43 lbs. of nitrogen to the minerals, varies from 8 to 11 bushels per acre; the total increase over the whole period being not quite 9 bushels per acre. The application of an additional 43 lbs. of nitrogen, or in other words, a total application of 86 lbs. of nitrogen, again

increases the amount of wheat by between 8 and 9 bushels over the whole period; the minerals alone yielding 15¼ bushels, the 43 lbs. of nitrogen 24⅛ bushels, and the 86 lbs. of nitrogen, 32¾ bushels per acre.

Comparing the four periods of 8 years with each other, it will be seen that the minerals alone, during the last period of 8 years gave 6½ bushels per acre less than during the first period; while the 43 lbs. of nitrogen yielded 7½ bushels per acre, and the 86 lbs. of nitrogen also 7½ bushels per acre, less during the last than during the first period. The reduction therefore would appear to be due to some cause which equally affected the three crops.

The addition of another 43 lbs. of nitrogen, by the application of 129 lbs. of the substance, proved far less effective than the previous additions, as instead of being from 8 to 9 bushels, the average increase was only 3½ bushels per acre; the average of the whole period of 32 years being, for the highest manure—where the 129 lbs. of nitrogen was applied—36¼ bushels per acre, and where 86 lbs. of nitrogen was applied, 32¾ bushels per acre.

The total increase obtained by this large amount of nitrogen (129 lbs.), in excess of the produce obtained by the mineral manures alone, amounted only to 21 bushels per acre per annum; it is therefore quite evident that in this experiment the nitrogen applied was in excess of the quantity which could be utilised by the crop; and even in the best season of growth, 1863, when the plot which received 86 lbs. of nitrogen yielded 53½ bushels per acre, the plot receiving 129 lbs. only yielded 2 bushels more!

The average yield of wheat in Great Britain is estimated by us at 28 bushels, and by others at 30 bushels per acre. The crop obtained by 86 lbs. of nitrogen appears to have quite reached, if it has not exceeded the profitable limit of growth; and it is only a rise in the price of wheat—and not lower prices—that could justify the outlay in manure which would be required to grow a larger crop. We have abundant evidence that a considerable amount of the nitrogen of the salts of ammonia has been converted into nitric acid, and washed into the drains, chiefly during the winter. At the time of the application of the nitrate of soda in the spring, the plots receiving ammonia-salts in the autumn had already lost more or less nitrogen; and until 1878 the trial of the relative crop-producing power of nitrogen as ammonia, and as nitric acid in the form of nitrate of soda, was not carried out on equal terms. For the crops of 1878–83, plot 7 A and B has received its salts of ammonia in the spring, while we have another plot, similarly manured,

which receives these salts in the autumn; and although the spring-sown ammonia has given the largest produce, still, the difference between the two crops is by no means what we might have expected from the known loss by drainage which took place when the manure was autumn-sown.

In the autumn of 1881 the soil of the various experimental plots was sampled to the depth of 27 inches. Between the application of the salts of ammonia in the spring and the time of sampling, only a small amount of drainage had taken place, but the nitric acid in the soil and drainage water did not account for the nitrogen which had been applied in the salts of ammonia, but had not been taken up by the crop, and the question arises whether there has been loss by destruction and evolution of free nitrogen, or whether any considerable amount of the ammonia has remained unnitrified in the soil, which would be in a much drier state in the spring and summer than during the autumn and winter.

It was not until after the experiment had been carried on for 8 years that the spring-sown nitrate showed a superiority over the autumn-sown salts of ammonia; but during the first 3 years, there were no minerals, and there was much less nitrate, applied to the nitrate plot (9 A). During the next 3 periods of 8 years each, the produce by the nitrate was considerably in excess; though in 6 of the last 8 years the ammonia-salts were applied in the spring. Over the whole period of 32 years the nitrate gave an increase, over the salts of ammonia, of $3\frac{1}{2}$ bushels per acre per annum, the produce of the ammonia-salts being $32\frac{3}{4}$ bushels, and that of the nitrate $36\frac{1}{4}$ bushels per acre.

The produce of the spring-sown nitrate supplying 86 lbs. of nitrogen is exactly equal to that of the chiefly autumn-sown salts of ammonia supplying 129 lbs., both giving $36\frac{1}{4}$ bushels per acre; and if we take the total crop (corn and straw), which is by far the best measure of the power of a manure to produce growth, we find that the 86 lbs. of nitrogen as nitrate of soda produced 6982 lbs., and the 129 lbs. of nitrogen in salts of ammonia 6832 lbs. of total produce per acre.

Although there is often a strong prejudice against the use of nitrate of soda, it is evident from this example that, when judiciously applied, its properties as a manure are higher than those of salts of ammonia. We may add, that when used continuously for 32 years its power to produce growth appears to increase, rather than to diminish, as during the last 16 years the total produce per acre per annum of 9 A, in excess of the produce of plot 7—each receiving the same amount of nitrogen—has been 7084 lbs. as against 5313 lbs.; a difference of 1771 lbs. of total produce per acre per annum in favour of the nitrate.

Plots 16 A and 16 B.

The Unexhausted Residue of Manures.

From 1852 to 1864, inclusive, these two plots received a mixed mineral manure and 800 lbs. of salts of ammonia, an amount which furnished to the soil annually 172 lbs. of nitrogen. It is very rarely that a sufficiently large crop of wheat is grown to remove one-half of this quantity of nitrogen.

In 1863 and 1864 the seasons were highly favourable for the growth of wheat; and as the size of the crop is regulated very much by the amount of nitrogen at its disposal, the two seasons were well adapted for ascertaining how much of this very large application could be employed in the growth of the crop.

In 1863 the yield of plot 16 was 56 bushels per acre, and in 1864, 51 bushels per acre. But plots 8 A and B produced 56 bushels and 50 bushels in the same two years, by means of an application of 600 lbs. of ammonia-salts; and as the additional 200 lbs. applied to 16 A and B only added 1 bushel to the crop, it was quite evident that we had reached the possible limits of growth on 8 A and B, even in seasons so favourable. It did not indeed seem likely—and the result afterwards confirmed the view—that such favourable seasons would occur again in a period of 20 years. Under these circumstances we decided to stop all further manuring after 1864, with the view of obtaining information, which might prove to be very valuable, in regard to the unexhausted residue of the manure employed.

The following table (p. 54) gives the produce of plot 16 for the last 2 years during which it received manure; and for the 19 succeeding years, during which it was unmanured: also for comparison there is given the produce of plot 5, which received an annual dressing of minerals alone.

It will be seen that in the first year after the manures were stopped, the produce of plot 16 was 32 bushels, or 18 bushels in excess of that grown on plot 5. In the next year, plot 16 gave 17¼ bushels, and plot 5 gave 13 bushels, a difference of only 4 bushels in favour of plot 16. In each of the next two years, plot 16 yielded 5 bushels in excess of plot 5. In the fifth year, the total produce, corn and straw, on plot 16 was only 104 lbs. more, and in the sixth year it was even 7 lbs. per acre less, than on plot 5. During the next 6 years, however, the total produce of plot 16 exceeded that of plot 5 in amounts varying from 109 lbs. to 221 lbs. It was, therefore, not until 12 years after the last application, that all influence due to the previous manuring ceased.

TABLE XXVII.—Showing the PRODUCE of the last TWO CROPS on PLOT 16, which received for 13 YEARS in succession an ANNUAL DRESSING of MIXED MINERALS, and SALTS of AMMONIA containing 172 lbs. of NITROGEN; followed by 19 UNMANURED CROPS. And for comparison, the produce of PLOT 5, which received MINERAL MANURES only over the whole period.

	Dressed Corn in Bushels per Acre.		Total Produce (Corn and Straw), lbs.	
	Plot 5, Minerals Alone.	Plot 16, Minerals and 172 lbs. Nitrogen.	Plot 5, Minerals Alone.	Plot 16, Minerals and 172 lbs. Nitrogen.
1863	19⅜	55⅞	3017	10,525
1864	16⅞	51⅛	2462	9,348
	Minerals	Unmanured	Minerals	Unmanured
1865	14¼	32⅜	2091	5,007
1866	13¼	17⅜	2303	3,081
1867	9¼	14⅝	1613	2,512
1868	17⅜	22⅜	2481	3,503
1869	15⅜	16¼	2543	2,647
1870	18⅞	18¼	2564	2,557
1871	11¼	13½	2207	2,380
1872	12⅜	13⅛	2166	2,387
1873	12⅜	12⅜	1806	1,921
1874	13	11⅞	1674	1,892
1875	9½	10⅛	1714	1,829
1876	10½	11	1429	1,538
1877	11⅛	9⅞	1570	1,340
1878	14⅜	13⅜	2222	2,181
1879	5⅛	4⅞	1238	1,154
1880	17½	14⅛	2818	2,383
1881	12¾	13½	1709	1,736
1882	12½	10¾	2057	1,925
1883	15¾	15⅞	2147	2,131

With regard to the large crop grown the first year after the manure was stopped, we are inclined to think it was mainly due to some of the nitrogen of the salts of ammonia not having been washed out of the soil. The year of the last application, 1864, was one of exceptional drought; in fact, it was the driest year that has been experienced at Rothamsted since the commencement of our experiments; and it is probably owing to this that, at all events a portion, of the produce of the first year was due. While the excess of produce obtained on plot 16, as compared with plot 5, during the next 11 years, is probably due to the slow decay and nitrification of the stubble, and underground roots, of the very large crops which had been grown on this plot for so many years.

During the 13 years of the annual application of 800 lbs. of salts of ammonia, considerably more than 1000 lbs. of the nitrogen applied to the soil was not recovered in the crops. It is therefore hardly possible to suppose that the nitrogen (about

60 lbs.) contained in the 6663 lbs. of total produce obtained in excess of that grown on plot 5, during the next 12 years, could have been derived directly from that supplied as manure, excepting so far as a portion of that of the first crop was concerned.

All the evidence, indeed, points to the residue of the crop itself as the source of the unexhausted manure; and it is quite certain that the very large amount of roots, and other residue, possessing considerable fertilising influence, which some of our rotation crops leave in the ground, have much to do with their value as restorative crops. In 1865 samples of soil were taken from various plots in the experimental wheat field, and submitted to analysis; and the percentage of nitrogen in the first 9 inches of soil was higher on plot 16 than on any other plot receiving artificial manures; while, in 1881, after 17 unmanured crops had been taken, when the soil was again analysed, it was found that the percentage of nitrogen was considerably reduced, and it was in fact then not much higher than that on the unmanured plot.

Farmyard Manure.

From the commencement of the continuous wheat experiments, one plot has received annually 14 tons of ordinary farmyard-manure per acre. No attempt has been made to ascertain by means of sampling and analysis the composition of the manure applied, for two reasons: (1) in the earlier years of the experiments, the importance of knowing the exact amount of the various ingredients applied to the soil was not well understood; (2) later on, the uncertainty of the results obtained in a very careful attempt to ascertain the exact composition of some box-dung at Woburn, led us to trust to an estimate of the composition based on numerous analyses of farmyard-manure, rather than to attempt to determine the composition by direct sampling and analysis.

The following table gives the estimated amount of some of the more important ingredients supplied to the soil annually in the 14 tons of farmyard-manure, as also the amount of ingredients supplied in the artificial manure on plot 7 :—

TABLE XXVIII.

	Dry organic Matter.	Nitrogen.	Phosphate of Lime.	Potash.
	lbs.	lbs.	lbs.	lbs.
Dung, Plot 2	8540	200	155	168
Artificial, Plot 7.. ..	..	86	140	100*

* 150 lbs. 7 years, 1852–8, 100 lbs. each year since.

Although the ingredients furnished to the soil of plot 7 differ greatly from those furnished by the dung, the average amount of produce is very nearly the same on the two plots, as will be seen in the following table:—

TABLE XXIX.—Showing the AVERAGE AMOUNTS of DRESSED CORN, and TOTAL PRODUCE (CORN and STRAW), on PLOT 2, MANURED with 14 TONS of FARMYARD-MANURE per ACRE per ANNUM; and on PLOT 7, MANURED with MINERALS and SALTS of AMMONIA, over PERIODS of 8 YEARS.

	Dressed Corn per Acre, Bushels.		Total Produce per Acre, (Corn and Straw), lbs.	
	Farmyard-Manure; 14 tons.	Minerals and Salts of Ammonia, = 86 lbs. Nitrogen.	Farmyard-Manure; 14 tons.	Minerals and Salts of Ammonia, = 86 lbs. Nitrogen.
8 years, 1852-1859 ..	34⅜	35½	6100	6490
8 years, 1860-1867 ..	35⅜	36¼	5926	6262
8 years, 1868-1875 ..	35¼	31	5932	5379
8 years, 1876-1883 ..	28⅜	28	4798	5248
32 years, 1852-1883 ..	33½	32¾	5689	5845
40 years with farmyard dung	32⅜	..	5516	..

Taking the whole period of thirty-two years—during which the two plots respectively received the same manure each year—it will be seen that the difference in the produce is less than one bushel per acre per annum; the dung yielding an average of 33½ bushels per acre, and the artificial manures of 32¾ bushels per acre. While of the total produce, corn and straw, the artificial manures on plot 7 gave an increase over that on plot 2 of 156 lbs. per acre per annum.

The most striking contrast between the two manures which give these very nearly identical results, is, that while the farmyard dung furnishes to the soil a large amount of organic matter, the artificial manure supplies none.

On plot 2, each year, about 8540 lbs. of organic matter were supplied to the soil, whilst the crop grown would not contain more than one-half as much. Yet the artificial manures, which supplied no organic matter whatever, produced a crop which contained rather the larger amount of organic matter of the two: and we have further evidence to show that by merely increasing the amount of nitrogen, a still larger amount of organic matter can be obtained in the crop. Thus, plot 8—which received

129 lbs. of nitrogen each year (still much less than that supplied in the dung), gave, over a period of 32 years, a total produce, corn and straw, of 6832 lbs. per acre, or 1143 lbs. more than that obtained by the farmyard-manure on plot 2.

It is quite evident from these results, that the amount of non-nitrogenous organic matter in the crop bears no relation to that supplied in the manure; and that the atmosphere, and not the soil, is the source of this supply.

The farmyard-manure not only furnished a large amount of non-nitrogenous organic matter to the soil, but it also furnished a larger amount of nitrogen than the artificial manures on plot 7. To produce a crop equal to that grown by the artificial manures on plot 7, we estimate that the farmyard-manure supplied to the soil more than twice as much nitrogen as that supplied by the artificial manures.

In the two years 1863 and 1864, the farmyard-manure applied to plot 2 was estimated to supply 400 lbs. of nitrogen, and the total produce amounted to 13,653 lbs.; while that of plot 16, which received 344 lbs. of nitrogen in salts of ammonia, was 19,873 lbs.; or in other words, there were, in the two years, 6220 lbs. excess of crop on the artificially manured plot!

As so much less growth is obtained from a given amount of nitrogen in dung, than from the same amount in salts of ammonia, or nitrate of soda, it is evident that the nitrogen in these substances must be in different chemical combinations.

In the soil, the nitrogen, which constitutes one of the most important elements in what we describe as permanent fertility, is always in combination with carbon. In this form it is both insoluble and inactive, and, for most crops at any rate, it only becomes available when, by the process of nitrification, it ceases to be in combination with carbon.

In dung, by far the greater part of the nitrogen is in combination with carbon; and, when we consider the various substances which make up the mass of the manure, we recognise at once that the periods of their decay, or nitrification, must vary greatly. The carbon may be separated from the nitrogen in urine in the course of a very short time, while it may take many years to nitrify portions of the nitrogenous organic matter of straw, especially on heavy land.

We have mentioned that in consequence of the inactive condition of much of the nitrogen in dung, it requires a considerably larger application of that substance, to grow the same amount of crop as that produced by a much smaller application of nitrogen in the more active form of ammonia-salts, or nitrates. This being the case, it is evident that in the soil where dung has been employed, we ought to find a larger amount both of carbon and

nitrogen, than in the soil where artificial manures have been used.

The evidence which we possess on this point is both interesting and instructive.

On the Underground Fertility of Plots 2, 3, *and* 7.

Although the nitrogen supplied to the land in the 14 tons of dung was considerably in excess of the amount supplied to plot 7 in the salts of ammonia, still the produce of wheat was nearly the same on the two plots; while the produce on plot 8 —which received a larger amount of salts of ammonia—was much higher than that on plot 2, although the nitrogen supplied was still considerably less than that contained in the farmyard-manure.

The great distinction between the two manures is, however, due to the nitrogen in the dung being chiefly in combination with carbon, and very little is yet known in regard to the various compounds of carbon existing in the soil.

In agriculture, we know that by the continual application of dung to the soil, as is the case in a garden, the soil increases in fertility, however much we may crop it. Some compounds of carbon and nitrogen are exceedingly durable, a familiar instance of which is to be found in coal; while in coke, nearly one-half of the nitrogen contained in the coal appears to be retained, although the latter has been exposed to a red heat. As regards dung, therefore—which is made up of urine (and some other secretions), the indigestible portions of food, and straw—we might expect to find that the process of its decay and parting with its carbon would extend over very different periods of time.

The soil of the dunged plot has been sampled and analysed on four different occasions. These analyses form a portion of an immense series of soil analyses which have been made from time to time of the soils of the various experimental and other fields at Rothamsted.

Some analyses have been made of subsoils taken to a depth of 9 feet from the surface, but the greater portion of the samples do not extend below 27 inches, each sample representing 9 inches of depth.

The great advantage to be derived from taking a large number of samples, and making a large number of analyses is, that we are thus enabled to form a better judgment as to the value and applicability of each separate result. In the present instance, however, our object is rather to point out the circumstances under which fertility accumulates in the soil, than to attempt to measure its exact amount.

We estimate that within 27 inches from the surface, the nitrogen on plot 2 will amount to more than 8000 lbs. per acre; and that it would exceed the amount, to the same depth, on plot 7 by more than 1700 lbs., and that on the permanently unmanured plot (3) by more than 2200 lbs.

By far the largest difference in the nitrogen of the three plots is found in the first 9 inches from the surface. To that depth the dunged land contained nearly double the amount of nitrogen which is found on plot 3, and more than one and a half times as much as is found on plot 7; and we estimate that plot 3, after the removal of forty unmanured crops of wheat in succession, still contains about 2400 lbs. of nitrogen in the first 9 inches from the surface; this, in fact, represents the residue of the natural fertility, or, to use a word imported into the Agricultural Holdings Act, the inherent capability of the soil.

The relation between the carbon and nitrogen in these three soils, which differ so greatly in their total amount of nitrogen, indicates that they do not differ much in their character. On the unmanured land the amount of carbon to 1 of nitrogen is not quite 10; on plot 7 it is 10½ to 1; and on the land which receives dung it is not quite 12 to 1. Now the unmanured plot has received neither carbon nor nitrogen in manure; plot 7 has received a very large amount of nitrogen, but no carbon; while plot 2 has received a very large amount of both carbon and nitrogen. The relation of the carbon to the nitrogen in the farmyard-manure is about 20 to 1; this proportion is totally different from what we find in the soil.

The close relation between the carbon and nitrogen in the soils of plot 3 and plot 7 indicates that the larger amount of nitrogen found in the soil of plot 7 is not due to the direct storing up of ammonia by the soil, but to the nitrogen forming part of vegetable growth, and being thus stored up in the stubble and roots.

If the nitrogen of the salts of ammonia had been stored up in any form except that of vegetable growth, the relation of carbon to nitrogen would have been lower on plot 7 than on plot 3, instead of which it is higher. There is also very clear evidence, derived from analyses of the soils of plot 3 and plot 7, that of the two the latter contains by far the larger amount of unexhausted fertility.

In the adjoining field, where barley is grown continuously, we have not only the evidence of the same accumulation having taken place where farmyard-manure was employed, as shown by analysis, but we have the evidence of the crops themselves.

For twenty years in succession, 14 tons of farmyard dung were applied to one plot of barley, after which period the plot was divided into two; on one half the dung was continued as before, and on the other half it was stopped. Up to the present time 12 unmanured crops have been taken, which yielded an average of 34½ bushels per acre, and, as the last crop in a rather favourable season (1883) exceeded 35 bushels, there is evidence of a long future before the fertility due to the residue of the twenty years' application of dung will be exhausted.

In the same field all the plots which have been manured with rape-cake showed by analysis that the soil contained a considerably larger amount of nitrogen than any of the plots where minerals, or minerals with salts of ammonia or nitrate, had been used. While therefore fertility may be stored up in the soil in the form of such mineral substances as potash or phosphate, it does not appear that the more valuable substance, nitrogen, can be stored up unless as united with carbon. Or, in other words, while the soil fixes potash and phosphoric acid independently of vegetation, nitrogen is only fixed by the agency of vegetation.

SUMMARY AND GENERAL CONCLUSIONS.

The Soil.

1. A soil which in the ordinary course of agriculture would have received an application of manure before another crop was grown, has produced forty crops of wheat in succession, averaging 14 bushels per acre, solely by means of its existing fertility.

2. At the commencement of the experiments the soil contained a large amount of organic nitrogen, derived from the *débris* of pre-existing vegetation. It also contained a large amount of the mineral food of plants.

3. Every year a certain proportion of the organic nitrogen has been nitrified by the agency of organisms existing in the soil.

4. Part of the nitrates formed has been employed in the growth of the wheat crop; part has been washed out of the soil or otherwise lost.

5. The loss of nitric acid is greater in wet seasons, and the amount taken up by the wheat crop is in consequence smaller. Comparatively dry seasons should therefore be favourable for the production of large crops of wheat.

6. The stock of soil fertility in the form of organic nitrogen has been considerably reduced during the forty years that the experiments have been carried on; and the amount of such reduc-

tion has been ascertained by analyses of the soil made at different periods. The stock of both potash and phosphoric acid has also been largely reduced.

7. Although so much soil fertility has been removed, the stock that remains would appear to be sufficient to grow crops of wheat for a very long period; the produce, however, must in process of time necessarily be lower than it has hitherto been.

Manures.

8. Mineral manures alone have added very slightly to the produce grown upon the unmanured land.

9. Manures containing nitric acid alone, or some compound of nitrogen which is easily nitrified, have considerably increased the crop.

10. The soil therefore contained a stock of minerals which the wheat crop was unable to make use of, owing to the insufficient supply of nitrogen in some available form.

11. Manures consisting of potash, phosphoric acid, and ammonia or nitrates, appear competent to grow large crops of wheat continuously.

12. A given weight of nitrogen as nitric acid, has produced more growth in the wheat crop than the same weight of nitrogen in salts of ammonia.

13. The amount of nitrogen supplied in the manures is very much in excess of the amount recovered in the increase of the crops.

14. After a certain amount of growth has been reached, each increase of crop requires a proportionately larger application of manure. When the price of grain is high, larger crops can be grown more profitably than when the price is low.

15. When farmyard dung is employed to grow wheat, a considerably larger amount of nitrogen must be applied to produce a given increase in the crop, as much of the nitrogen contained in the dung is not in an active condition.

16. A given weight of nitrogen, in the form of nitric acid, will produce more growth in the crop to which it is applied than the same weight of nitrogen in dung; but the influence of the nitrate upon succeeding crops will be very much less.

17. There is no evidence to show whether the whole available effect of the nitrogen in one manure is greater than it is in the other.

Unexhausted Manures.

18. In the absence of vegetation, or when applied to crops in excess of their requirement, both potash and phosphoric acid form insoluble compounds with the soil and become available for future crops.

19. In the absence of vegetation, or when the amount supplied is in excess of the requirements of the crop, nitrates and salts of ammonia do not appear to form permanent compounds with the soil, but, on the contrary, are liable to be washed out by rain, or to be otherwise lost.

20. The application of a larger amount of nitrogen, as nitrates or salts of ammonia, than the crop can utilize, does not appear to prevent the nitrification of the organic nitrogen of the soil.

21. The stock of nitrogen of the soil itself, therefore, may be reduced, although the annual application of nitrogen may be much in excess of the amount of that substance removed in the crop.

22. When large crops of wheat have been grown by the application of nitrates or salts of ammonia, with mineral manures, the soil does not appear to have gained or lost fertility. Nitrification of the organic matter in the soil may have gone on as usual, but the loss has been made good by the amount of nitrogen stored up in the stubble and underground roots of the large crops so grown.

23. When dung is applied continuously to land, the accumulation of unexhausted fertility becomes very large, and the removal by crops of the substance accumulated would extend over a long series of years.

24. Dung applied to land in the ordinary processes of agriculture will not be entirely exhausted until a considerable number of years have elapsed from the time of its application.

APPENDIX-TABLES.

I—XXVII.

[*To face p.* 62.

APPENDIX-TABLE I.—MANURES p
20 YEARS 1864–83, and also
in all 32 YEARS; with the exc

M (p. 63).

PLOTS.	Farm-yard-Manure.	Sulphate of Potash (1).	Sulphate of Soda. (1).	Sulphate of Magnesia. (1).
	Tons.	lbs.	lbs.	lbs.
0	..	..	..	..
1	..	400	200	200
2	14	..	..	..
3	Unmanured		..	..
4	Unmanured		..	..
5A	..	200	100	100
5B	..	200	100	100
6A	..	200	100	100
6B	..	200	100	100
7A	..	200	100	100
7B	..	200	100	100
8A	..	200	100	100
8B	..	200	100	100
(2) 9A	..	200	100	100
(2) 9B	..	..	..	..
10A	..	..	..	..
10B	..	..	..	..
11A	..	..	..	..
11B	..	..	..	..
12A	..	..	366½	..
12B	..	..	366½	..
13A	..	200	..	..
13B	..	200	..	..
14A	..	..	..	280
14B	..	..	..	280
(4) 15A	..	200	100	100
(4) 15B	..	200	100	100
(5) 16A	..	200	100	100
(5) 16B	..	200	100	100
(6) 17A	..	200	100	100
(6) 17B	..	200	100	100
(6) 18A	..	..	..	..
(6) 18B	..	..	..	..
(7) 19	..	..	..	..
(8) 20	Unmanured		..	..
21	..	200	100	100
22	..	200	100	100

ft, free of the book, as it es.)

lbs. per acre per annum
lbs. per acre.—Sulphate
100 lbs. is now applied.
per annum.—Sulphate
d 14B.
1853 and 1854, 275 lbs.
these 3 years.

hate made with 150 lbs.
ake has been omitted on
s on 15A, and 300 lbs.
200 lbs. Sulphate, and
manures.
865 and since.
plots the manures have
lts on Plots 17A and 17B,
B in one year; mineral
lots 18A and 18B in the

1700 lbs. per acre per
= to 400 lbs. Ammonia-

portion (20–1) has since
ner portion (20–2) being

68 to 1879 inclusive, cut
ous season), was applied
17 (or 18); also for the
he straw of the previous
lot 15. For the crop of
tued.
—From the commence-
clusive, the dung, the
, &c., were sown in the
and 1853, when, owing
id sown in the autumn,
wn; and for the crops
Plots 15A and 15B were
r, always been sown in
at loss of the nitrogen
was decided to apply
the autumn, and the
keeping on Plots 15A
in the autumn. This

APPENDIX-TABLE II.—PRODUCE of the 21st SEASON, 1863–4. SEED (RED ROSTOCK) sown NOVEMBER 16, 1863; CROP cut AUGUST 12–16, and carted AUGUST 19 and 20, 1864.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.			Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.		Weight per Bushel.									
	bush.	pcks	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	19	0	62·0	64	1241	1575	2816	163	225	388	5·4	78·8
1	14	3¾	62·0	37	962	1296	2258	−116	− 54	−170	3·9	74·2
2	40	0	62·5	96	2595	3893	6488	1517	2543	4060	3·8	66·7
3	16	1¾	62·0	56	1078	1350	2428	..	..	..	5·5	79·8
4	17	0¼	61·9	27	1085	1337	2422	7	− 13	− 6	2·6	81·2
5A	16	1	62·1	44	1052	1293	2345	− 26	− 57	− 83	4·4	81·4
5B	17	2	62·0	35	1121	1458	2579	43	108	151	3·2	76·9
6A	31	1½	62·0	70	2016	3630	5646	938	2280	3218	3·6	55·5
6B	30	3¼	62·0	68	1978	3127	5105	900	1777	2677	3·6	63·3
7A	44	1¼	63·0	117	2912	4897	7809	1834	3547	5381	4·2	59·5
7B	47	1	63·1	104	3087	5043	8130	2009	3693	5702	3·5	61·2
8A	49	3	63·5	124	3284	5585	8869	2206	4235	6441	3·9	58·8
8B	50	0	63·5	124	3300	5590	8890	2222	4240	6462	3·9	59·0
9A	51	0¼	62·6	134	3330	5985	9315	2252	4635	6887	4·2	55·7
9B	33	1	61·7	128	2182	3287	5469	1104	1937	3041	6·2	66·4
10A	32	0¼	61·8	112	2093	2832	4925	1015	1482	2497	5·6	73·9
10B	36	0¾	62·1	148	2395	3247	5642	1317	1897	3214	6·6	73·8
11A	34	2	59·7	148	2210	3440	5650	1132	2090	3222	7·2	64·2
11B	38	1½	59·0	128	2394	3878	6272	1316	2528	3844	5·6	61·7
12A	44	1¾	62·6	99	2881	4315	7196	1803	2965	4768	3·6	66·8
12B	44	3	62·4	93	2882	4356	7238	1804	3006	4810	3·3	66·2
13A	42	2¾	63·2	88	2785	4480	7265	1707	3130	4837	3·2	62·2
13B	43	2¾	63·4	111	2882	4620	7502	1804	3270	5074	4·0	62·4
14A	41	0¼	63·1	149	2740	4003	6743	1662	2653	4315	5·8	68·4
14B	41	3¾	62·8	110	2745	4107	6852	1667	2757	4424	4·2	66·8
15A	37	2¼	63·1	90	2459	4003	6462	1381	2653	4034	3·8	61·4
15B	37	1	63·0	74	2421	4010	6431	1343	2660	4003	3·2	60·4
16A	50	3½	63·2	118	3333	6003	9336	2255	4653	6908	3·7	55·5
16B	51	1½	63·2	125	3370	5990	9360	2292	4640	6932	3·8	56·3
17A	36	2¼	62·6	88	2378	3920	6298	1300	2570	3870	3·8	60·7
17B	35	3¼	62·6	74	2316	3667	5983	1238	2317	3555	3·3	63·2
18A	17	0¼	61·3	33	1078	1460	2538	none	110	110	3·2	73·8
18B	18	1¼	61·6	43	1169	1600	2769	91	250	341	3·8	73·0
19	37	0½	62·3	127	2440	3363	5803	1362	2013	3375	5·5	72·6
20	13	2	63·3	73	929	1332	2261	−149	− 18	−167	8·6	69·7
21	24	3¼	62·3	80	1625	2323	3948	547	973	1520	5·2	70·0
22	25	1½	62·0	68	1642	2180	3822	564	830	1394	4·3	75·3

APPENDIX-TABLE III.—PRODUCE of the 22nd SEASON, 1864–5. SEED (RED ROSTOCK) SOWN NOVEMBER 10, 1864; CROP cut AUGUST 10–12, 1865.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.											
	Quantity.		Weight per Bushel.	Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	15	2	59·0	78	993	1135	2128	165	102	267	8·5	87·5
1	12	1½	59·0	71	802	1064	1866	— 26	31	5	9·7	75·3
2	37	0½	61·5	100	2384	3100	5484	1556	2067	3623	4·4	76·9
3	13	1¼	60·6	22	828	1033	1861	..	..	..	2·7	80·2
4	14	2¾	60·3	63	950	1162	2112	122	129	251	7·1	81·7
5A	14	0¾	61·0	43	910	1132	2042	82	99	181	5·0	80·4
5B	14	0¾	60·8	59	920	1220	2140	92	187	279	6·9	75·4
6A	24	3¼	61·0	78	1589	1978	3567	761	945	1706	5·1	80·3
6B	25	0	60·9	101	1621	2063	3684	793	1030	1823	6·6	78·6
7A	40	0	61·6	87	2550	3598	6148	1722	2565	4287	3·5	70·9
7B	40	1¾	61·7	115	2609	3740	6349	1781	2707	4488	4·6	69·8
8A	43	3½	61·3	120	2509	4517	7326	1981	3484	5465	4·5	62·2
8B	43	1¼	61·5	190	2857	4682	7539	2029	3649	5678	7·1	61·0
9A	44	0¼	61·1	189	2881	4682	7563	2053	3649	5702	7·0	61·5
9B	29	2¼	59·5	248	2005	3137	5142	1177	2104	3281	14·1	63·9
10A	25	0¾	59·6	145	1649	2385	4034	821	1352	2173	9·7	69·1
10B	30	1¾	59·8	119	1938	2677	4615	1110	1644	2754	6·5	72·4
11A	26	2¼	57·2	178	1696	2397	4093	868	1364	2232	11·7	70·8
11B	28	0¼	57·3	172	1780	2662	4442	952	1629	2581	10·7	66·9
12A	35	0¾	60·0	163	2277	3067	5344	1449	2034	3483	7·7	74·3
12B	33	3¾	60·3	172	2220	3148	5368	1392	2115	3507	8·4	70·5
13A	35	3	61·1	143	2328	3243	5571	1500	2210	3710	6·6	71·8
13B	38	2	61·1	154	2506	3518	6024	1678	2485	4163	6·6	71·2
14A	36	0¼	60·3	170	2345	3127	5472	1517	2094	3611	7·8	75·0
14B	37	0¼	60·4	150	2390	3195	5585	1562	2162	3724	6·7	74·8
15A	35	1¾	60·9	135	2291	3142	5433	1463	2109	3572	6·3	72·9
15B	36	1	61·6	177	2411	3375	5786	1583	2342	3925	7·9	71·4
16A	32	0	61·8	135	2113	2837	4950	1285	1804	3089	6·8	74·5
16B	32	2¼	61·7	114	2125	2938	5063	1297	1905	3202	5·7	72·3
17A	16	3½	60·9	68	1097	1488	2585	269	455	724	6·6	73·7
17B	17	0¾	60·6	58	1098	1452	2550	270	419	689	5·5	75·6
18A	30	0½	60·1	105	1916	2785	4701	1088	1752	2840	5·8	68·8
18B	32	3	60·3	91	2065	2877	4942	1237	1844	3081	4·6	71·8
19	32	3½	58·9	147	2083	2987	5070	1255	1954	3209	7·6	69·7
20	13	2¾	60·2	67	889	1307	2196	61	274	335	8·1	68·0
21	18	1¼	58·0	66	1128	1458	2586	300	425	725	6·3	77·4
22	19	0¾	58·3	76	1195	1527	2722	367	494	861	6·8	78·3

APPENDIX-TABLE IV.—PRODUCE of the 23rd SEASON, 1865–6. SEED (RED ROSTOCK) sown NOVEMBER 10, 1865; CROP cut AUGUST 12–15, and carted AUGUST 27, 1866.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)						Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	16 3	60·0	27	1033	1729	2762	256	460	716	2·7	59·7
1	11 1½	59·8	25	709	1301	2010	− 68	32	− 36	3·6	54·5
2	32 2½	61·7	59	2070	4058	6128	1293	2789	4082	2·9	51·0
3	12 0½	61·3	33	777	1269	2046	..	..	..	4·4	61·2
4	13 1½	60·9	38	852	1419	2271	75	150	225	4·7	60·0
5A	13 0½	60·8	38	832	1454	2286	55	185	240	4·5	57·2
5B	13 1½	61·0	35	843	1476	2319	66	207	273	3·5	57·1
6A	19 3½	61·0	43	1255	2207	3462	478	938	1416	3·6	56·9
6B	21 0½	61·0	47	1333	2289	3622	556	1020	1576	3·7	58·2
7A	30 0½	61·1	60	1897	3844	5741	1120	2575	3695	3·3	49·4
7B	29 3	60·9	72	1885	3923	5808	1108	2654	3762	4·0	48·1
8A	32 0	60·0	136	2057	5318	7375	1280	4049	5329	7·1	38·7
8B	32 1	60·2	110	2051	5306	7357	1274	4037	5311	5·7	38·7
9A	32 2	60·6	94	2061	5316	7377	1284	4047	5331	4·8	38·8
9B	30 3	59·9	138	1979	4682	6661	1202	3413	4615	7·5	42·3
10A	26 1	61·2	88	1693	2792	4485	916	1523	2439	5·5	60·7
10B	28 2	61·5	94	1848	3047	4895	1071	1778	2849	5·4	60·7
11A	27 3½	60·8	95	1789	3130	4919	1012	1861	2873	5·6	57·2
11B	28 0½	60·5	98	1800	3252	5052	1023	1983	3006	5·7	55·4
12A	28 1½	61·0	72	1804	3473	5277	1027	2204	3231	4·2	51·9
12B	28 0½	61·3	83	1812	3538	5350	1035	2269	3304	4·8	51·2
13A	24 0½	62·0	77	1576	3350	4926	799	2081	2880	5·1	47·0
13B	25 1½	61·5	92	1647	3623	5270	870	2354	3224	5·9	45·5
14A	28 1½	61·1	80	1813	3563	5376	1036	2294	3330	4·6	50·9
14B	27 2½	61·3	77	1768	3367	5135	991	2098	3089	4·5	52·5
15A	26 0	61·6	54	1655	3053	4708	878	1784	2662	3·4	54·2
15B	26 1½	61·4	70	1690	3297	4987	913	2028	2941	4·3	51·3
16A	17 0½	61·9	51	1111	1955	3066	334	686	1020	4·8	56·8
16B	17 2	61·6	50	1127	1968	3095	350	699	1049	4·7	57·3
17A	27 0½	61·3	71	1739	3365	5104	962	2096	3058	4·3	51·7
17B	25 2½	61·1	78	1643	3582	5225	866	2313	3179	5·0	45·9
18A	12 0½	60·6	38	775	1502	2277	− 2	233	231	5·2	51·6
18B	13 0½	60·8	43	846	1533	2379	69	264	333	5·4	55·2
19	26 2½	59·7	113	1698	3347	5045	921	2078	2999	7·1	50·7
20	13 2½	59·1	32	837	1627	2464	60	358	418	3·9	51·4
21	17 2	59·9	26	1072	2104	3176	295	835	1130	2·5	51·0
22	18 1½	59·8	23	1123	2127	3250	346	858	1204	2·1	52·8

APPENDIX-TABLE V.—PRODUCE of the 24th SEASON, 1866–7. SEED (RED ROSTOCK) sown NOVEMBER 8, 1866; CROP cut AUGUST 23 and 24, and carted AUGUST 30, 1867.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.											
	Quantity.		Weight per Bushel.	Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	10	2½	58·7	41	664	1320	1984	132	347	479	6·6	50·3
1	7	3½	57·9	34	487	944	1431	− 45	− 29	− 74	7·5	51·6
2	27	2½	61·4	61	1755	3136	4891	1223	2163	3386	3·6	56·0
3	8	3½	56·1	33	532	973	1505	..	..	..	6·6	54·7
4	9	1	58·6	41	583	999	1582	51	26	77	7·6	58·4
5A	9	2½	59·7	33	609	1099	1708	77	126	203	5·8	55·4
5B	8	3½	59·0	29	551	966	1517	19	− 7	12	5·5	57·1
6A	15	1½	60·6	43	972	1684	2656	440	711	1151	4·7	57·7
6B	16	0½	60·5	55	1033	1762	2795	501	789	1290	5·6	58·7
7A	22	3½	61·3	62	1469	2796	4265	937	1823	2760	4·4	52·5
7B	21	1½	60·7	67	1365	2727	4092	833	1754	2587	5·2	50·1
8A	29	1½	60·8	103	1896	4103	5999	1364	3130	4494	6·0	46·2
8B	31	1½	60·5	104	2008	4288	6296	1476	3315	4791	5·5	46·8
9A	29	0½	59·9	112	1855	4918	6773	1323	3945	5268	6·4	37·7
9B	22	0½	57·4	124	1892	3246	4638	860	2273	3133	9·8	42·9
10A	18	0½	57·9	77	1123	2023	3146	591	1050	1641	7·3	55·5
10B	19	1½	59·3	88	1237	2138	3375	705	1165	1870	7·7	57·9
11A	21	3½	59·1	64	1360	2218	3578	828	1245	2073	4·9	61·3
11B	22	1	59·8	84	1416	2402	3818	884	1429	2313	6·3	59·0
12A	25	0½	60·2	65	1577	2628	4205	1045	1655	2700	4·3	60·0
12B	23	3½	60·6	59	1511	2685	4196	979	1712	2691	4·1	56·3
13A	23	1½	60·8	51	1471	2662	4133	939	1689	2628	3·6	55·3
13B	24	1	60·7	58	1529	2822	4351	997	1849	2846	4·0	54·2
14A	23	0½	59·8	61	1450	2598	4048	918	1625	2543	4·4	55·8
14B	22	1½	59·6	70	1398	2537	3935	866	1564	2430	5·2	55·1
15A	22	3½	60·2	51	1427	2670	4097	895	1697	2592	3·7	53·5
15B	23	0½	59·5	56	1435	2730	4165	903	1757	2660	4·1	52·6
16A	14	1½	59·4	35	890	1583	2473	358	610	968	4·1	56·2
16B	14	3½	59·1	33	907	1643	2550	375	670	1045	3·8	55·2
17A	10	3½	59·2	34	678	1193	1871	146	220	366	5·3	56·8
17B	10	2½	57·6	42	658	1257	1915	126	284	410	6·8	52·3
18A	22	3	59·1	38	1384	2558	3942	852	1585	2437	2·8	54·1
18B	24	1½	57·5	45	1448	2675	4123	916	1702	2618	3·2	54·1
19	23	3½	56·7	63	1421	2620	4041	889	1647	2536	4·7	54·2
20	7	0½	56·4	28	433	948	1381	− 99	− 25	−124	7·0	45·6
21	12	2½	59·3	40	787	1388	2175	255	415	670	5·4	56·7
22	12	2½	59·3	41	791	1377	2168	259	404	663	5·4	57·4

APPENDIX-TABLE VI.—PRODUCE of the 25th SEASON, 1867–8. SEED (RED ROSTOCK) sown NOVEMBER 2, 1867; CROP cut JULY 22–28, and carted JULY 25–29, 1868.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)						Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	22 1¼	61·4	33	1404	1855	3259	350	882	1232	2·4	75·7
1	20 2¼	60·0	27	1259	1594	2853	205	621	826	2·2	79·0
2	41 3	61·6	33	2604	4190	6794	1550	3217	4767	1·3	62·1
3	16 2½	61·0	41	1054	973	2027	..	..	..	4·0	108·4
4	17 2	61·6	27	1103	1345	2448	49	372	421	2·5	82·0
5A	16 1¼	62·2	28	1044	1250	2294	− 10	277	267	2·8	83·5
5B	18 3½	63·5	28	1226	1442	2668	172	469	641	2·4	85·0
6A	27 3	62·4	51	1782	2437	4219	728	1464	2192	3·0	73·1
6B	28 3¾	63·2	57	1887	2700	4587	833	1727	2560	3·1	69·9
7A	40 2	61·5	36	2528	4017	6545	1474	3044	4518	1·5	62·9
7B	39 0¾	60·6	33	2408	3680	6088	1354	2707	4061	1·4	65·4
8A	44 0½	62·1	51	2794	4683	7477	1740	3710	5450	1·9	59·7
8B	48 3½	61·9	40	3069	4933	8002	2015	3960	5975	1·3	62·2
9A	47 3¼	61·1	46	2970	5180	8150	1916	4207	6123	1·6	57·3
9B	27 1	62·0	111	1799	2742	4541	745	1769	2514	6·6	65·6
10A	24 3	61·9	93	1627	2163	3790	573	1190	1763	6·1	75·2
10B	27 2¾	62·4	118	1846	2364	4210	792	1391	2183	6·9	78·1
11A	33 1¾	62·4	124	2211	2790	5001	1157	1817	2974	5·9	79·2
11B	33 2½	62·2	118	2207	2850	5057	1153	1877	3030	5·6	77·4
12A	39 2	63·6	101	2611	3421	6032	1557	2448	4005	4·0	76·4
12B	40 1	63·3	74	2620	3653	6273	1566	2680	4246	2·9	71·7
13A	37 3½	63·0	34	2417	4010	6427	1363	3037	4400	1·4	60·3
13B	40 2½	63·2	45	2614	4040	6654	1560	3067	4627	1·7	64·7
14A	41 3¾	63·9	37	2716	3685	6401	1662	2712	4374	1·4	73·7
14B	41 1¾	64·1	98	2754	3668	6422	1700	2695	4395	3·7	75·1
15A	44 0½	63·8	43	2856	4656	7512	1802	3683	5485	1·5	61·3
15B	41 2¼	63·3	63	2692	4223	6915	1638	3250	4888	2·4	63·7
16A	23 0	62·9	34	1481	2125	3606	427	1152	1579	2·3	69·7
16B	22 2¼	62·7	25	1438	1962	3400	384	989	1373	1·8	73·3
17A	38 0¼	63·4	53	2466	3767	6233	1412	2794	4206	2·2	65·5
17B	36 3	64·2	55	2413	3527	5940	1359	2554	3913	2·4	68·4
18A	18 0¾	62·7	28	1168	1537	2705	114	564	678	2·5	76·0
18B	19 0¾	62·9	31	1239	1672	2911	185	699	884	2·6	74·1
19	36 3¾	62·9	98	2422	3161	5583	1368	2188	3556	4·2	76·6
20(1)	..	..	..	..	..	..	..	..	..	..	..
21	26 1	62·6	44	1687	2267	3954	633	1294	1927	2·7	74·4
22	24 3¾	62·8	48	1615	2300	3915	561	1327	1888	3·1	70·2

(1) Produce unknown, owing to a mistake at Harvest.

APPENDIX-TABLE VII.—PRODUCE of the 26th SEASON, 1868–9. SEED (RED ROSTOCK) sown NOVEMBER 3, 1868; CROP cut AUGUST 16–18, and carted AUGUST 21 and 24, 1869.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw.)		Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.										
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.		
0	15 1¼	58·1	66	955	1493	2448		107	143	250	7·5	64·0
1	12 0¾	58·2	36	744	1180	1924		−104	−170	−274	5·1	63·1
2	38 1	56·9	80	2256	3937	6193		1408	2587	3995	3·7	57·3
3	14 1	56·1	48	848	1350	2198		..	..	..	5·9	62·8
4	14 3¼	57·1	50	896	1405	2301		48	55	103	5·9	63·7
5A	15 2¼	56·8	45	928	1514	2442		80	164	244	5·1	61·3
5B	15 3¼	57·0	53	956	1687	2643		108	337	445	5·9	56·7
6A	21 0¼	57·0	69	1273	2250	3523		425	900	1325	5·7	56·6
6B	22 0¼	57·3	80	1345	2280	3625		497	930	1427	6·4	59·0
7A	28 2¼	57·7	101	1748	3114	4862		900	1764	2664	6·1	56·1
7B	28 1	57·2	156	1771	3309	5080		923	1959	2882	9·7	53·5
8A	25 0¼	57·0	107	2105	3898	6003		1257	2548	3805	5·4	54·0
8B	34 1¾	57·5	108	2086	3937	6023		1238	2587	3825	5·4	53·0
9A	39 0	57·1	140	2368	4930	7298		1520	3580	5100	6·3	48·0
9B	24 0½	54·6	136	1452	3475	4927		604	2125	2729	10·3	41·8
10A	20 1	54·9	99	1210	2265	3475		362	915	1277	8·9	53·4
10B	19 0¼	55·6	125	1188	2186	3374		340	836	1176	11·8	54·3
11A	24 0¼	56·2	91	1443	2568	4011		595	1218	1813	6·8	56·2
11B	20 1¼	55·1	128	1251	2345	3596		403	995	1398	11·4	53·4
12A	26 1¾	58·1	102	1638	2637	4275		790	1287	2077	6·6	62·1
12B	28 0¼	57·9	100	1726	3008	4734		878	1658	2536	6·1	57·4
13A	25 2¾	59·3	110	1631	2826	4457		783	1476	2259	7·3	57·7
13B	28 3¼	59·0	125	1827	3267	5094		979	1917	2896	7·3	55·9
14A	28 1	58·5	128	1778	3076	4854		930	1726	2656	7·8	57·8
14B	27 0¼	58·1	126	1701	2999	4700		853	1649	2502	8·0	56·7
15A	26 2¼	58·1	93	1635	2954	4589		787	1604	2391	6·0	55·4
15B	27 0½	59·3	88	1694	3008	4702		846	1658	2504	5·5	56·3
16A	16 1¾	58·6	54	1019	1678	2697		171	328	499	5·6	60·8
16B	15 3¼	58·1	64	982	1614	2596		134	264	398	7·0	60·9
17A	15 1	58·1	64	952	1570	2522		104	220	324	7·2	60·7
17B	17 0	57·3	86	1059	1829	2888		211	479	690	8·9	57·9
18A	23 0¼	58·7	78	1431	2433	3864		583	1083	1666	5·7	58·8
18B	22 3¼	58·0	94	1418	2460	3878		570	1110	1680	7·1	57·6
19	23 0¾	56·7	133	1447	2566	4013		599	1216	1815	10·1	56·4
20	13 0¾	56·9	77	826	1253	2079		− 22	− 97	−119	10·2	65·9
21	20 2¾	58·1	63	1260	2115	3375		412	765	1177	5·3	59·6
22	15 0¾	58·1	60	942	1483	2425		94	133	227	6·8	63·5

APPENDIX-TABLE VIII.—PRODUCE of the 27th SEASON, 1869–70. SEED (RED ROSTOCK) sown NOVEMBER 3, 1869; CROP cut AUGUST 5–12, and carted AUGUST 11–15, 1870.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).		Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.										
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.		
0	21 2¾	62·1	69	1415	1239	2654		459	193	652	5·1	114·3
1	16 0¾	62·5	45	1056	1087	2143		100	41	141	4·5	97·1
2	36 2	63·4	44	2359	2733	5092		1403	1687	3090	1·9	86·3
3	14 3¾	61·8	81	956	1046	2002		..	..	..	3·3	91·3
4	15 2¾	62·6	39	1023	1107	2130		67	61	128	4·0	92·4
5A	18 0¾	62·6	40	1178	1302	2480		222	256	478	3·6	90·5
5B	19 0¾	62·6	28	1228	1419	2647		272	373	645	2·3	86·6
6A	29 3	63·0	63	1936	2269	4205		980	1223	2203	3·4	85·3
6B	31 0¼	63·1	58	2023	2438	4461		1067	1392	2459	3·0	83·0
7A	39 2¾	63·3	59	2568	3148	5716		1612	2102	3714	2·4	81·6
7B	41 1¼	63·2	56	2672	3284	5956		1716	2238	3954	2·1	81·4
8A	45 3¾	63·7	66	2992	3635	6627		2036	2589	4625	2·3	82·3
8B	44 2	63·8	100	2939	3699	6638		1983	2653	4636	3·6	79·5
9B	45 2	62·7	89	2940	3911	6851		1984	2865	4849	3·1	75·2
9B	26 1¾	61·3	115	1735	2080	3815		779	1034	1813	7·1	83·4
10A	21 2¾	60·8	100	1420	1627	3047		464	581	1045	7·6	87·3
10B	23 0¾	60·8	88	1496	1748	3244		540	702	1242	6·2	85·6
11A	25 0¼	60·8	128	1653	1917	3570		697	871	1568	8·4	86·2
11B	25 1¾	60·7	139	1682	1895	3577		726	849	1575	9·0	88·8
12A	36 2	62·4	72	2347	2577	4924		1391	1531	2922	3·2	91·1
12B	34 0	62·5	93	2218	2503	4721		1262	1457	2719	4·4	88·6
13A	35 2¼	63·7	64	2328	2815	5143		1372	1769	3141	2·8	82·7
13B	38 1¼	63·9	82	2535	2993	5528		1579	1947	3526	3·4	84·7
14A	35 0¼	63·2	117	2336	2584	4920		1380	1538	2918	5·4	90·4
14B	36 1	62·7	125	2398	2588	4986		1442	1542	2984	5·5	92·6
15A	38 0¾	63·8	68	2502	3072	5574		1546	2026	3572	2·8	81·5
15B	38 2¼	63·9	80	2550	3119	5669		1594	2073	3667	3·3	81·8
16A	18 1½	63·2	48	1207	1365	2572		251	319	570	4·2	88·4
16B	18 0¾	63·3	56	1208	1333	2541		252	287	539	4·9	90·7
17A	33 1½	63·6	63	2187	2628	4815		1231	1582	2813	3·0	83·2
17B	35 1	63·7	70	2315	2715	5030		1359	1669	3028	3·1	85·3
18A	17 3	63·1	56	1175	1259	2434		219	213	432	5·0	93·3
18B	20 1	63·3	53	1335	1488	2823		379	442	821	4·1	89·7
19	32 1	62·3	128	2137	2242	4379		1181	1196	2377	6·4	95·4
20	14 2¾	62·5	23	943	1175	2118		− 13	129	116	2·5	80·3
21	25 3	63·1	39	1666	1949	3615		710	903	1613	2·5	85·4
22	26 2¼	63·0	49	1723	1996	3719		767	950	1717	2·9	86·3

APPENDIX-TABLE IX.—PRODUCE of the 28th SEASON, 1870–1. SEED (RED ROSTOCK) sown NOVEMBER 1 and 2, 1870; CROP cut AUGUST 21–23, and carted AUGUST 28–31, 1871.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.			Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.		Weight per Bushel.									
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	13	3¾	56·5	102	889	1566	2455	274	466	740	13·0	56·7
1	10	1½	57·0	97	685	1451	2136	70	351	421	16·5	47·2
2	38	3¾	60·0	161	2498	4506	7004	1883	3406	5289	6·9	55·5
3	9	1½	54·8	106	615	1100	1715	..	..	..	20·9	55·9
4	10	1½	57·0	118	708	1277	1985	93	177	270	20·1	55·4
5A	11	0	56·4	97	718	1340	2058	103	240	343	15·6	53·6
5B	12	3	56·7	103	827	1529	2356	212	429	641	14·3	54·1
6A	16	3¾	56·8	138	1099	2290	3389	484	1190	1674	14·3	48·0
6B	17	0	56·3	123	1078	2304	3382	463	1204	1667	12·8	46·8
7A	22	0¾	56·0	263	1503	3093	4596	888	1993	2881	21·2	48·6
7B	22	1½	57·3	245	1520	3076	4596	905	1976	2881	19·2	49·4
8A	26	1	57·1	247	1745	3716	5461	1130	2616	3746	16·5	47·0
8B	29	0½	58·3	240	1940	4150	6090	1325	3050	4375	14·2	46·7
9A	34	1¾	58·6	210	2228	4909	7137	1613	3809	5422	10·5	45·4
9B	17	2½	52·4	171	1093	2425	3518	478	1325	1803	18·6	45·1
10A	10	0½	53·8	130	675	1252	1927	60	152	212	24·0	53·9
10B	10	0	53·8	125	663	1339	2002	48	239	287	23·2	49·5
11A	12	0½	54·3	139	795	1448	2243	180	348	528	21·2	54·9
11B	9	3¾	53·8	137	668	1279	1947	53	179	232	25·8	52·2
12A	22	2¾	56·5	177	1458	2700	4158	843	1600	2443	13·8	54·0
12B	19	1¾	55·6	178	1259	2440	3699	644	1340	1984	16·4	51·6
13A	28	1	57·6	184	1812	3433	5245	1197	2333	3530	11·3	52·8
13B	32	0¾	58·2	185	2050	4125	6175	1435	3025	4460	9·9	49·7
14A	26	2¾	57·0	213	1728	3063	4791	1113	1963	3076	14·1	56·4
14B	21	3¾	56·7	246	1490	2937	4427	875	1837	2712	19·8	50·8
15A	29	1¼	59·0	177	1905	3597	5502	1290	2497	3787	10·2	53·0
15B	32	0¼	58·7	209	2093	3808	5901	1478	2708	4186	11·1	55·0
16A	13	1	57·2	78	836	1510	2346	221	410	631	10·2	55·4
16B	13	3	56·5	64	841	1573	2414	226	473	699	8·2	53·5
17A	13	1½	56·0	74	824	1608	2432	209	508	717	9·8	51·3
17B	18	2	56·8	78	1129	2032	3161	514	932	1446	7·4	55·6
18A	28	0¼	58·6	118	1763	3254	5017	1148	2154	3302	7·2	54·2
18B	28	3	58·0	124	1792	3428	5220	1177	2328	3505	7·4	52·3
19	22	1¼	56·0	165	1413	2688	4101	798	1588	2386	13·2	52·6
20	10	1¾	55·8	83	665	1350	2015	50	250	300	14·3	49·3
21	15	0¾	56·8	115	979	1873	2852	364	773	1137	13·4	52·3
22	16	3	56·9	113	1067	1871	2938	452	771	1223	11·8	57·0

APPENDIX-TABLE X.—PRODUCE of the 29th SEASON, 1871–2. SEED (RED ROSTOCK) sown OCTOBER 28, 1871; CROP cut AUGUST 16 and 17, and carted AUGUST 20 and 21, 1872.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)						Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	17 1	58·7	46	1060	1873	2933	355	721	1076	4·6	56·6
1	10 3½	57·9	72	701	1270	1971	− 4	118	114	11·5	55·2
2	32 1½	60·7	80	2046	3761	5807	1341	2609	3950	4·1	54·4
3	10 2¾	59·0	76	705	1152	1857	..	..	..	12·1	61·2
4	11 1¼	57·6	65	717	1216	1933	12	64	76	10·0	59·0
5A	12 3¾	60·2	58	836	1301	2137	131	149	280	7·4	64·3
5B	12 2½	59·8	77	833	1361	2194	128	209	337	10·1	61·2
6A	20 3¼	60·1	58	1308	2770	4078	603	1618	2221	4·6	47·2
6B	20 0¾	60·3	82	1299	2363	3662	594	1211	1805	6·7	55·0
7A	30 1¼	60·4	103	1936	3611	5547	1231	2459	3690	5·6	53·6
7B	29 0¼	60·0	191	1937	4043	5980	1232	2891	4123	10·9	47·9
8A	37 0¼	60·5	164	2404	5430	7834	1699	4278	5977	7·3	44·3
8B	34 0¼	60·4	188	2244	4712	6956	1539	3560	5099	9·1	47·6
9A	40 2¾	60·0	124	2565	6527	9092	1860	5375	7235	5·1	39·3
9B	23 1½	55·5	138	1434	3210	4644	729	2058	2787	10·6	44·7
10A	18 0	56·8	157	1178	2442	3620	473	1290	1763	15·4	48·2
10B	18 2¾	55·9	122	1166	2440	3606	461	1288	1749	11·6	47·8
11A	27 0	59·5	160	1766	3387	5153	1061	2235	3296	10·0	52·2
11B	27 1¾	58·6	152	1758	3450	5208	1053	2298	3351	9·4	51·0
12A	30 0	60·1	126	1928	3933	5861	1223	2781	4004	7·0	49·0
12B	28 2	59·4	130	1824	3388	5212	1119	2236	3355	7·7	53·9
13A	30 1¼	60·3	117	1946	3988	5934	1241	2836	4077	6·4	48·8
13B	29 2	60·8	130	1923	3808	5731	1218	2656	3874	7·3	50·5
14A	31 0¾	59·8	129	1995	3850	5845	1290	2698	3988	6·9	51·8
14B	29 1¾	59·5	144	1897	3725	5622	1192	2573	3765	8·2	50·9
15A	30 0¼	60·5	146	1961	4011	5972	1256	2859	4115	8·1	48·9
15B	32 1¼	60·7	133	2095	4134	6229	1390	2982	4372	6·8	50·7
16A	13 3¼	59·5	54	874	1642	2516	169	490	659	6·6	53·3
16B	12 1⅝	59·3	55	791	1466	2257	86	314	400	7·5	54·0
17A	25 3	60·8	119	1685	3249	4934	980	2097	3077	7·6	51·9
17B	26 0¼	60·5	95	1673	3358	5031	968	2206	3174	6·0	49·8
18A	12 1¾	59·3	83	818	1579	2397	113	427	540	11·2	51·8
18B	13 1¾	59·5	61	862	1761	2623	157	609	766	7·7	49·0
19	27 2¾	59 6	145	1794	3303	5097	1089	2151	3240	8·8	54·3
20	11 1½	57·1	48	696	1247	1943	− 9	95	86	7·3	55·8
21	20 3¼	59·6	71	1312	2216	3528	607	1064	1671	5·7	59·2
22	20 0¼	59·8	58	1257	2030	3287	552	878	1430	4·8	61·9

APPENDIX-TABLE XI.—PRODUCE of the 30th SEASON, 1872–3. SEED (RED ROSTOCK) sown NOVEMBER 8, 1872; CROP cut AUGUST 15–19, and carted SEPTEMBER 2, 1873.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)						Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	15 2¼	57·6	51	950	1183	2133	249	281	530	5·7	80·4
1	10 2	56·6	42	636	966	1602	− 65	64	− 1	7·0	65·8
2	26 3	58·1	67	1622	2463	4085	921	1561	2482	4·3	65·9
3	11 2⅝	57·0	35	701	902	1603	..	..	..	5·3	77·7
4	12 0½	57·2	56	749	998	1747	48	96	144	8·1	75·0
5A	12 3½	56·8	40	771	1054	1825	70	152	222	5·5	73·1
5B	12 2	57·0	42	754	1032	1786	53	130	183	5·8	73·0
6A	14 3½	57·5	52	905	1513	2418	204	611	815	6·1	59·8
6B	16 3⅝	56·6	58	1015	1527	2542	314	625	939	6·1	66·4
7A	21 0½	57·0	59	1264	1852	3116	563	950	1513	4·9	68·2
7B	22 3	57·3	77	1381	2190	3571	680	1288	1968	5·9	63·0
8A	25 3⅝	57·5	77	1566	2477	4043	865	1575	2440	5·1	63·2
8B	29 0¼	56·3	83	1720	2850	4570	1019	1948	2967	5·4	60·3
9A	35 3½	57·1	119	2160	3932	6092	1459	3030	4489	5·8	54·9
9B	21 3½	54·9	104	1303	2358	3661	602	1456	2058	8·7	55·2
10A	19 2½	56·1	74	1173	1635	2808	472	733	1205	6·8	71·7
10B	20 2½	56·5	80	1247	1642	2889	546	740	1286	6·8	75·9
11A	19 0½	56·0	83	1153	1583	2736	452	681	1133	7·8	72·8
11B	19 1⅜	55·1	81	1152	1578	2730	451	676	1127	7·5	73·0
12A	22 1⅜	56·9	82	1360	1943	3303	659	1041	1700	6·4	70·0
12B	23 1½	56·5	80	1401	2037	3438	700	1135	1835	6·1	68·8
13A	22 3½	57·4	81	1395	2036	3431	694	1134	1828	6·1	68·5
13B	24 0	57·3	64	1440	2107	3547	739	1205	1944	4·6	68·3
14A	23 3⅝	57·0	61	1426	2120	3546	725	1218	1943	4·5	67·3
14B	24 1	56·6	78	1452	2172	3624	751	1270	2021	5·7	66·9
15A	32 3½	57·7	71	1963	2992	4955	1262	2090	3352	3·7	65·6
15B	32 1½	57·9	73	1941	3165	5106	1240	2263	3503	3·9	61·3
16A	12 2½	57·4	40	759	1130	1889	58	228	286	5·5	67·2
16B	13 0	57·0	36	778	1174	1952	77	272	349	4·9	66·3
17A	10 2½	56·6	38	639	1092	1731	− 62	190	128	6·3	58·6
17B	12 3½	57·6	51	789	1108	1897	88	206	294	7·0	71·2
18A	19 2	57·3	61	1177	1805	2982	476	903	1379	5·5	65·2
18B	21 0½	57·6	58	1274	2007	3281	573	1105	1678	4·7	63·5
19	20 0	56·7	80	1212	1858	3070	511	956	1467	7·7	65·3
20	12 2	56·9	47	758	1098	1856	57	196	253	6·6	69·0
21	14 0½	56·9	52	853	1258	2111	152	356	508	6·4	67·8
22	18 0½	56·9	54	1084	1663	2747	383	761	1144	5·3	65·2

APPENDIX-TABLE XII.—PRODUCE of the 31st SEASON, 1873–4. SEED (RED ROSTOCK) SOWN OCTOBER 29 and 30, 1873; CROP cut AUGUST 8–11, and carted AUGUST 15 and 17, 1874.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.			Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.		Weight per Bushel.									
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	16	3½	59·1	18	1014	1328	2342	320	338	658	1·8	76·4
1	11	1½	59·6	14	690	972	1662	− 4	− 18	− 22	2·0	71·0
2	39	1	60·2	70	2431	4439	6870	1737	3449	5186	3·0	54·8
3	11	1¾	58·3	27	694	990	1684	..	..	..	4·0	70·1
4	12	1	58·8	13	734	999	1733	40	9	49	1·8	73·5
5A	12	2¼	59·1	23	768	845	1613	74	−145	− 71	3·1	90·8
5B	13	1¾	59·1	24	820	914	1734	126	− 76	50	3·0	89·7
6A	25	2¾	59·7	17	1550	2212	3762	856	1222	2078	1·1	70·1
6B	25	3½	59·5	21	1562	2230	3792	868	1240	2108	1·4	70·0
7A	39	1¼	59·9	78	2436	4508	6944	1742	3518	5260	3·3	54·0
7B	39	2¼	59·7	96	2461	4782	7243	1767	3792	5559	4·1	51·5
8A	41	3¼	60·1	121	2637	6182	8819	1943	5192	7135	4·8	42·7
8B	39	0½	59·6	138	2471	5944	8415	1777	4954	6731	5·9	41·6
9A	38	0¾	60·4	105	2409	5012	7421	1715	4022	5737	4·6	48·1
9B	21	2	57·5	31	1269	2166	3435	575	1176	1751	2·5	58·6
10A	25	1	56·5	48	1476	1977	3453	782	987	1769	3·4	74·7
10B	27	0¾	56·9	136	1686	2387	4073	992	1397	2389	8·8	70·6
11A	36	2	57·9	95	2208	3166	5374	1514	2176	3690	4·5	69·7
11B	29	1	58·3	156	1859	3077	4936	1165	2087	3252	9·2	60·4
12A	40	3¾	59·4	65	2497	4011	6508	1803	3021	4824	2·7	62·3
12B	38	0	59·7	88	2359	3774	6133	1665	2784	4449	3·9	62·5
13A	36	3	60·6	75	2303	3952	6255	1609	2962	4571	3·4	58·3
13B	37	1¾	60·4	42	2301	4002	6303	1607	3012	4619	1·9	57·5
14A	37	3½	59·9	32	2294	3570	5864	1600	2580	4180	1·4	64·2
14B	35	1½	59·2	93	2187	3618	5805	1493	2628	4121	4·4	60·4
15A	27	3	61·3	22	1724	2609	4333	1030	1619	2649	1·3	66·1
15B	30	2½	60·9	36	1901	2943	4844	1207	1953	3160	1·9	64·6
16A	9	0½	60·2	20	564	913	1477	−130	− 77	−207	3·7	61·8
16B	14	2½	60·0	39	915	1392	2307	221	402	623	4·4	65·7
17A	32	3¼	60·6	40	2027	3501	5528	1333	2511	3844	2·0	57·9
17B	33	2½	60·9	46	2094	3473	5567	1400	2483	3883	2·2	60·3
18A	13	3	58·8	24	832	1047	1879	138	57	195	3·0	79·5
18B	14	0½	58·8	39	871	1012	1883	177	22	199	4·7	86·1
19	37	3¼	58·9	68	2293	3136	5429	1599	2146	3745	3·1	73·1
20	13	3	59·2	32	845	1312	2157	151	322	473	3·9	64·4
21	22	3½	59·5	30	1391	1666	3057	697	676	1373	2·2	83·5
22	21	1½	59·3	21	1289	1547	2836	595	557	1152	1·6	83·3

APPENDIX-TABLE XIII.—PRODUCE of the 32nd SEASON, 1874–5. SEED (RED ROSTOCK) sown OCTOBER 26 and 27, 1874; CROP cut AUGUST 16–21, and carted AUGUST 24 and 25, 1875.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).		Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.										
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.		
0	10 1½	59·4	51	663	1150	1813		96	142	238	8·3	57·6
1	8 0½	58·5	41	511	868	1379		− 56	−140	−196	8·7	58·9
2	28 3½	60·6	147	1890	3719	5609		1323	2711	4034	8·4	50·8
3	8 2½	60·0	50	567	1008	1575		..	..	..	9·7	56·2
4	7 2½	59·7	51	508	910	1418		− 59	− 98	−157	11·3	55·8
5A	8 1	59·2	37	526	1051	1577		− 41	43	2	7·6	50·1
5B	10 0½	59·5	46	653	1198	1851		86	190	276	7·6	54·5
6A	15 3½	60·7	86	1046	1899	2945		479	891	1370	8·9	55·1
6B	16 3½	59·8	80	1084	2117	3201		517	1109	1626	8·0	51·2
7A	25 0½	59·9	147	1652	3334	4986		1085	2326	3411	9·7	49·6
7B	26 2½	59·0	154	1723	3509	5232		1156	2501	3657	9·8	49·1
8A	31 0½	58·2	194	2006	4400	6406		1439	3392	4831	10·7	45·6
8B	28 2½	58·1	202	1867	4245	6112		1300	3237	4537	12·1	44·0
9A	30 2	57·9	198	1965	4747	6712		1398	3739	5137	11·2	41·4
9B	16 2	55·7	130	1050	2363	3413		483	1355	1838	14·1	44·4
10A	12 3	54·5	91	786	1574	2360		219	566	785	13·2	50·0
10B	14 2½	55·6	126	934	1782	2716		367	774	1141	15·5	52·4
11A	19 3½	55·5	111	1217	2392	3609		650	1384	2034	10·1	50·9
11B	15 3½	54·6	157	1026	2217	3243		459	1209	1668	18·0	46·3
12A	24 3½	58·1	135	1585	2972	4557		1018	1964	2982	9·3	53·3
12B	25 2½	57·2	112	1574	3104	4678		1007	2096	3103	7·7	50·7
13A	26 0½	60·4	92	1673	3299	4972		1106	2291	3397	5·8	50·7
13B	27 3½	60·0	93	1766	3231	4997		1199	2223	3422	5·6	54·7
14A	27 2½	59·0	120	1747	3060	4807		1180	2052	3232	7·4	57·1
14B	25 0	58·0	127	1576	3183	4759		1009	2175	3184	8·8	49·5
15A	23 2½	59·9	181	1594	2916	4510		1027	1908	2935	12·8	54·7
15B	27 2	60·6	163	1829	3491	5320		1262	2483	3745	9·8	52·4
16A	10 2	59·8	49	676	1222	1898		109	214	323	7·9	55·8
16B	9 3	59·5	35	613	1147	1760		46	139	185	6·0	53·4
17A	11 0½	58·9	41	691	1247	1938		124	239	363	6·3	55·4
17B	12 1	59·6	48	777	1450	2227		210	442	652	6·6	53·6
18A	25 1	59·2	74	1569	2916	4485		1002	1908	2910	4·9	53·8
18B	25 3½	58·9	76	1598	3096	4694		1031	2088	3119	5·0	51·6
19	22 3½	56·5	98	1392	2494	3886		825	1486	2311	7·6	55·8
20	8 0½	57·0	38	501	1028	1529		− 66	20	− 46	8·2	48·7
21	12 3½	59·9	66	842	1376	2218		275	368	643	8·5	61·2
22	13 3	60·2	67	893	1491	2384		326	483	809	8·1	59·9

APPENDIX-TABLE XIV.—PRODUCE of the 33rd SEASON, 1875–6. SEED (RED ROSTOCK) sown NOVEMBER 1 and 2, 1875; CROP cut AUGUST 8–19, and carted AUGUST 14–23, 1876.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.				
	Dressed Grain.			Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.	Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Quantity.		Weight per Bushel.									
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	11	3½	57·3	53	733	830	1563	233	188	421	7·8	88·3
1	7	2	56·8	18	440	571	1011	− 60	− 71	−131	3·1	77·0
2	23	3½	62·4	58	1545	2140	3685	1045	1498	2543	3·9	72·2
3	8	0½	59·0	21	500	642	1142	..	..	..	4·6	77·9
4	9	0	58·5	18	546	706	1252	46	64	110	3·6	77·4
5A	9	3¾	59·2	20	610	792	1402	110	150	260	3·4	77·0
5B	11	0¼	59·1	25	679	777	1456	179	135	314	3·9	87·4
6A	14	3½	61·9	41	962	1201	2163	462	559	1021	4·4	80·1
6B	16	2	62·2	56	1081	1393	2474	581	751	1332	5·4	77·6
7A	21	1¾	63·2	90	1444	2015	3459	944	1373	2317	6·6	71·6
7B	25	2	62·7	118	1719	2408	4127	1219	1766	2985	7·4	71·4
8A	30	2¾	63·1	121	2054	3083	5137	1554	2441	3995	6·2	66·6
8B	28	2	62·7	111	1895	2788	4683	1395	2146	3541	6·2	68·0
9A	33	1¼	62·7	168	2255	3584	5839	1755	2942	4697	8·0	62·9
9B	13	0	56·3	32	766	1217	1983	266	575	841	4·3	62·9
10A	12	0½	57·2	25	719	922	1641	219	280	499	3·6	78·0
10B	14	1¾	56·4	32	848	1270	2118	348	628	976	3·8	66·7
11A	15	1	59·6	54	963	1313	2276	463	671	1134	6·0	73·4
11B	13	1¾	58·4	49	832	1228	2060	332	586	918	6·3	67·8
12A	19	2¼	61·0	64	1260	1711	2971	760	1069	1829	5·4	73·7
12B	18	3	60·4	74	1206	1661	2867	706	1019	1725	6·5	72·6
13A	24	2	62·1	54	1575	2431	4006	1075	1789	2864	3·6	64·8
13B	25	3½	62·4	58	1669	2435	4104	1169	1793	2962	3·6	68·6
14A	22	3½	61·4	49	1454	2027	3481	954	1385	2339	3·5	71·7
14B	21	1	60·7	48	1338	1863	3201	838	1221	2059	3·7	71·8
15A	24	3	62·3	63	1602	2320	3922	1102	1678	2780	4·1	69·0
15B	26	0½	61·7	97	1709	2535	4244	1209	1893	3102	6·0	67·4
16A	10	3¾	58·5	18	658	841	1499	158	199	357	2·9	78·2
16B	11	0¼	58·4	25	669	908	1577	169	266	435	3·9	73·7
17A	27	0	61·1	59	1709	2605	4314	1209	1963	3172	3·5	65·6
17B	25	3½	60·6	43	1611	2474	4085	1111	1832	2943	2·7	65·1
18A	10	0½	58·3	19	609	898	1507	109	256	365	3·3	67·8
18B	10	2½	58·5	18	639	893	1532	139	251	390	2·9	71·6
19	19	1	57·6	37	1147	1566	2713	647	924	1571	3·3	73·3
20	7	1½	57·3	19	442	665	1107	− 58	23	− 35	4·5	66·4
21	10	3	57·4	64	681	935	1616	181	293	474	10·3	73·1
22	13	0¾	57·0	67	817	1214	2031	317	572	889	8·9	67·3

APPENDIX-TABLE XV.—PRODUCE of the 34th SEASON, 1876–7. SEED (RED ROSTOCK) sown OCTOBER 23, 1876; CROP cut AUGUST 18–24, and carted AUGUST 30, 1877.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.			Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.		Weight per Bushel.									
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	11	3½	59·0	23	728	908	1636	185	160	345	3·2	80·2
1	7	0½	59·3	16	434	521	955	−109	−227	−336	3·8	83·3
2	24	0½	59·1	54	1481	2266	3747	938	1518	2456	3·8	65·4
3	8	3½	58·9	19	543	748	1291	..	..	..	3·7	72·6
4	9	3½	57·3	23	584	807	1391	41	59	100	4·2	72·4
5A	11	0½	57·4	27	668	872	1540	125	124	249	4·2	76·6
5B	12	0½	56·8	21	708	892	1600	165	144	309	3·0	79·4
6A	14	2½	59·6	28	904	1172	2076	361	424	785	3·2	77·1
6B	14	1½	56·7	33	847	1179	2026	304	431	735	4·1	71·9
7A	20	2½	59·1	40	1259	1983	3242	716	1235	1951	3·3	63·5
7B	19	0½	59·3	34	1167	1687	2854	624	939	1563	3·0	69·2
8A	27	0½	59·4	49	1665	2477	4142	1122	1729	2851	3·1	67·2
8B	22	1	59·0	42	1354	2010	3364	811	1262	2073	3·2	67·4
9A	40	0½	57·9	60	2383	3852	6235	1840	3104	4944	2·6	61·9
9B	27	2½	58·0	48	1654	2540	4194	1111	1792	2903	3·0	65·1
10A	17	0½	57·5	43	1031	1322	2353	488	574	1062	4·4	78·0
10B	18	1	58·4	37	1105	1492	2597	562	744	1306	3·5	74·1
11A	18	3½	60·0	45	1182	1453	2635	639	705	1344	4·0	81·4
11B	16	3½	59·8	41	1046	1353	2399	503	605	1108	4·1	77·3
12A	19	3½	60·2	58	1249	1640	2889	706	892	1598	4·9	76·2
12B	15	3	59·9	51	994	1331	2325	451	583	1034	5·4	75·4
13A	18	2	60·1	54	1165	1581	2746	622	833	1455	4·9	73·7
13B	18	0	60·1	29	1108	1556	2664	565	808	1373	2·7	71·2
14A	19	0½	59·5	35	1170	1633	2803	627	885	1512	3·1	71·6
14B	18	0	57·2	34	1063	1503	2566	520	755	1275	3·4	70·8
15A	32	3½	58·9	44	1978	2817	4795	1435	2069	3504	2·3	70·0
15B	33	1½	59·6	44	2036	2759	4795	1493	2011	3504	2·2	73·8
16A	10	1	57·2	24	610	736	1346	67	− 12	55	4·1	82·8
16B	9	1½	58·9	15	567	767	1334	24	19	43	2·6	73·9
17A	10	0½	59·1	69	662	823	1485	119	75	194	11·7	80·4
17B	9	3½	58·6	15	591	728	1319	48	− 20	28	2·6	81·2
18A	11	2½	58·0	17	696	1038	1734	153	290	443	2·5	67·1
18B	13	2	58·8	21	816	1090	1906	273	342	615	2·7	74·9
19	19	1½	58·0	28	1156	1452	2608	613	704	1317	2·5	79·6
20	11	1½	58·1	33	694	994	1688	151	246	397	5·0	69·8
21	11	2½	58·5	30	710	1049	1759	167	301	468	4·5	67·7
22	21	0½	55·0	38	1197	1725	2922	654	977	1631	3·2	69·4

APPENDIX-TABLE XVI.—PRODUCE of the 35th SEASON, 1877–8. SEED (RED ROSTOCK) sown NOVEMBER 2 and 3, 1877; CROP cut AUGUST 1–10, and carted AUGUST 19, 1878.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.			Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.		Weight per Bushel.									
	bush.	pcks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	15	2	59·0	44	959	1420	2379	183	339	522	4·8	67·5
1	10	1½	59·1	41	654	1064	1718	−122	−17	−139	6·6	61·4
2	28	1	60·9	170	1890	4042	5932	1114	2961	4075	9·9	46·7
3	12	1¼	59·0	50	776	1081	1857	..	..	..	6·9	71·8
4	12	1¾	59·9	30	776	992	1768	none	−89	−89	4·0	78·3
5A	14	3	58·3	41	899	1324	2223	123	243	366	4·8	67·9
5B	14	2½	59·3	36	901	1320	2221	125	239	364	4·2	68·3
6A	22	1	61·1	64	1424	2813	4237	648	1732	2380	4·7	50·6
6B	23	0¾	60·5	64	1468	3074	4542	692	1993	2685	4·6	47·8
7A	30	1¼	60·6	159	1998	4804	6802	1222	3723	4945	8·7	41·6
7B	32	0¾	60·6	180	2132	5100	7232	1356	4019	5375	9·2	43·8
8A	37	3½	60·4	165	2452	6227	8679	1676	5146	6822	7·2	39·4
8B	38	1½	60·2	175	2485	6119	8604	1709	5038	6747	7·6	40·6
9A	37	0¾	59·2	131	2333	5624	7957	1557	4543	6100	5·9	41·5
9B	23	1½	56·9	78	1408	2897	4305	632	1816	2448	5·9	48·6
10A	27	1½	59·5	78	1708	2762	4470	932	1681	2613	4·8	61·9
10B	29	3¼	59·6	75	1853	2981	4834	1077	1900	2977	4·2	62·1
11A	29	2½	59·9	124	1894	4258	6152	1118	3177	4295	7·0	44·5
11B	29	2½	60·0	126	1903	4326	6229	1127	3245	4372	7·1	44·0
12A	28	3	60·5	168	1906	4479	6385	1130	3398	4528	9·7	42·6
12B	29	2½	60·8	165	1966	4824	6790	1190	3743	4933	9·1	40·7
13A	29	0	61·1	115	1888	4708	6596	1112	3627	4739	6·5	40·1
13B	29	3¾	60·6	103	1917	4664	6581	1141	3583	4724	5·7	41·1
14A	32	2	60·8	107	2085	5014	7099	1309	3933	5242	5·4	41·6
14B	31	2½	60·3	86	1994	4794	6788	1218	3713	4931	4·5	41·6
15A	20	3¾	59·6	85	1334	2931	4265	558	1850	2408	6·8	45·5
15B	23	0¾	60·1	102	1495	3211	4706	719	2130	2849	7·3	46·5
16A	13	3¾	59·3	35	862	1351	2213	86	270	356	4·2	63·8
16B	13	0¾	60·3	43	837	1312	2149	61	231	292	5·5	63·8
17A	29	1½	61·0	122	1914	4528	6442	1138	3447	4585	6·8	42·3
17B	28	2½	60·8	94	1834	4735	6569	1058	3654	4712	5·4	38·7
18A	15	0½	59·8	54	955	1514	2469	179	433	612	6·0	63·1
18B	15	1½	60·2	50	976	1596	2572	200	515	715	5·4	61·2
19	27	1¾	60·0	77	1723	3148	4871	947	2067	3014	4·7	54·7
20	14	1	57·7	41	863	1212	2075	87	131	218	5·0	71·2
21	19	1½	59·3	60	1208	1821	3029	432	740	1172	5·2	66·3
22	18	2¾	59·0	62	1163	1880	3043	387	799	1186	5·6	61·9

APPENDIX-TABLE XVII.—PRODUCE of the 36th SEASON, 1878–9. SEED (RED ROSTOCK) SOWN OCTOBER 30 and 31, 1878; CROP cut SEPTEMBER 4–17, and carted SEPTEMBER 22, 1879.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).		Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.										
	bush. pcks.	lbs.	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.		
0	4 2¾	54·0	65	318	691	1009		− 12	− 72	− 84	25·7	46·0
1	2 2¼	54·0	44	182	428	610		−148	−335	−483	31·9	42·5
2	16 0	56·8	153	1064	2239	3303		734	1476	2210	16·8	47·5
3	4 2¾	52·5	84	330	763	1093		..	..	..	34·0	43·3
4	4 1½	51·1	92	317	748	1065		− 13	− 15	− 28	41·2	42·4
5A	5 3	53·9	75	385	841	1226		55	78	133	24·2	45·8
5B	5 2¼	53·0	87	382	868	1250		52	105	157	29·3	44·0
6A	9 1¼	56·2	96	619	1400	2019		289	637	926	18·4	44·2
6B	11 2¾	56·7	100	762	1784	2546		432	1021	1453	15·1	42·7
7A	15 1	56·5	108	969	2890	3859		639	2127	2766	12·5	33·5
7B	17 1	56·8	153	1133	3133	4266		803	2370	3173	15·6	36·2
8A	20 0¼	56·7	177	1318	4069	5387		988	3306	4294	15·5	32·4
8B	21 0	56·2	206	1384	4283	5667		1054	3520	4574	17·5	32·3
9A	21 3¾	56·5	222	1462	4347	5809		1132	3584	4716	17·9	33·6
9B	4 2¼	49·8	119	345	1070	1415		15	307	322	52·5	32·3
10A	3 3¾	48·9	80	272	889	1161		− 58	126	68	41·4	30·5
10B	4 2¼	52·6	125	370	1006	1376		40	243	283	51·1	36·7
11A	11 0¾	55·5	168	788	2086	2874		458	1323	1781	27·1	37·8
11B	11 0¼	53·6	81	676	1955	2631		346	1192	1538	13·6	34·5
12A	13 3¼	56·4	132	913	2555	3468		583	1792	2375	16·9	35·7
12B	14 1	55·3	164	952	2384	3336		622	1621	2243	20·8	39·9
13A	14 0¾	57·5	148	964	2776	3740		634	2013	2647	18·1	34·7
13B	17 3¼	58·0	151	1188	3327	4515		858	2564	3422	14·6	35·7
14A	16 3	57·7	140	1105	3072	4177		775	2309	3084	14·5	36·0
14B	15 2¾	56·6	200	1089	2734	3823		759	1971	2730	22·5	39·8
15A	5 3¼	53·1	93	406	1019	1425		76	256	332	29·8	39·8
15B	4 3¾	52·5	73	333	792	1125		3	29	32	28·2	42·1
16A	5 1¼	52·8	80	359	808	1167		29	45	74	28·7	44·5
16B	4 1¼	52·9	92	321	819	1140		−9	56	47	40·3	39·2
17A	2 2¼	52·5	52	189	589	778		−141	−174	−315	38·1	32·0
17B	3 2¼	49·5	75	255	659	914		− 75	−104	−179	41·8	38·6
18A	19 3¼	58·7	121	1284	3283	4567		954	2520	3474	10·4	39·1
18B	20 3¼	57·9	123	1330	3406	4736		1000	2643	3643	10·2	39 1
19	8 0¾	53·6	135	573	1335	1908		243	572	815	30·7	42·9
20	4 1	53·0	71	296	745	1041		− 34	− 18	− 52	31·6	39·7
21	8 1¼	54·0	90	541	1138	1679		211	375	586	19·9	47·6
22	11 3¼	55·5	106	761	1798	2559		431	1035	1466	16·2	42·3

APPENDIX-TABLE XVIII.—PRODUCE of the 37th SEASON, 1879–80. SEED (RED ROSTOCK) sown OCTOBER 27 and 28, 1879; CROP cut AUGUST 14–20, and carted AUGUST 25, 1880.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)						Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 1 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.									
	bush. pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	16 0¾	58·6	41	990	1315	2305	301	166	467	4·3	75·3
1	11 0	57·6	21	655	1151	1806	− 34	2	− 32	3·3	56·9
2	38 1½	60·2	66	2373	3902	6275	1684	2753	4437	2·8	60·8
3	11 2	56·9	34	689	1149	1838	..	..	..	5·1	59·9
4	12 3	57·4	27	760	1263	2023	71	114	185	3·6	60·2
5A	18 2½	59·1	33	1128	1747	2875	439	598	1037	3·0	64·6
5B	16 3½	59·2	43	1038	1722	2760	349	573	922	4·3	60·3
6A	27 3	59·8	59	1718	3172	4890	1029	2023	3052	3·6	54·2
6B	26 0¼	59·8	51	1610	2649	4259	921	1500	2421	3·3	60·8
7A	34 2½	59·7	82	2149	4051	6200	1460	2902	4362	4·0	53·0
7B	34 1½	59·9	94	2149	3960	6109	1460	2811	4271	4·6	54·3
8A	37 2¾	59·6	127	2374	5135	7509	1685	3986	5671	5·6	46·2
8B	32 3½	58·5	106	2031	3817	5848	1342	2668	4010	5·5	53·2
9A	34 0¼	57·8	165	2130	4394	6524	1441	3245	4686	8·4	48·4
9B	10 1¾	53·5	95	654	1420	2074	− 35	271	236	17·0	46·1
10A	10 2½	54·9	62	645	1242	1887	− 44	93	49	10·6	51·9
10B	13 1¾	53·5	60	779	1631	2410	90	482	572	8·3	47·7
11A	27 0¼	58·4	94	1673	2868	4541	984	1719	2703	6·0	58·3
11B	24 2	57·3	117	1520	2835	4355	831	1686	2517	8·3	53·6
12A	30 3	59·2	101	1921	3589	5510	1232	2440	3672	5·5	53·5
12B	27 3½	58·7	104	1739	2939	4678	1050	1790	2840	6·4	59·2
13A	33 0½	59·9	85	2070	3859	5929	1381	2710	4091	4·3	53·7
13B	32 3½	59·4	78	2029	3649	5678	1340	2500	3840	4·0	55·6
14A	32 1	59·2	98	2007	3638	5645	1318	2489	3807	5·2	55·2
14B	29 2¾	57·8	96	1811	3009	4820	1122	1860	2982	5·6	60·2
15A	36 3½	60·8	82	2325	4234	6559	1636	3085	4721	3·6	54·9
15B	35 1¾	60·7	89	2242	3816	6058	1553	2667	4220	4·1	58·7
16A	14 2½	58·1	33	882	1736	2618	193	587	780	3·9	50·8
16B	14 0¾	58·5	56	885	1263	2148	196	114	310	6·8	70·1
17A	32 0	60·7	75	2017	3383	5400	1328	2234	3562	3·8	59·6
17B	33 2½	59 5	88	2083	3271	5354	1394	2122	3516	4·5	63·7
18A	14 2½	58·1	51	903	1340	2243	214	191	405	6·0	67·4
18B	15 1¼	57·7	53	935	1351	2286	246	202	448	6·0	69·2
19	32 2	58·4	157	2057	3254	5311	1368	2105	3473	8·2	63·2
20–1	20 3¼	60·0	65	1314	2120	3434	625	971	1596	5·2	62·0
20–2	12 3	56·6	49	771	1096	1867	82	− 53	29	6·8	70·3
21	16 2	57·3	46	992	1626	2618	303	477	780	4·8	61·0
22	26 1¾	57·3	66	1581	2469	4050	892	1320	2212	4·4	64·0

APPENDIX-TABLE XIX.—PRODUCE of the 38th SEASON, 1880–1. SEED (RED ROSTOCK) sown OCTOBER 25, 1880; CROP cut AUGUST 8–11, and carted AUGUST 29, and SEPTEMBER 1, 1881.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.											
	Quantity.		Weight per Bushel.	Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.		
	bush.	pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		
0	15	2½	54·2	63	909	973	1882	46	−173	−127	7·5	93·4
1	12	2¾	53·7	45	728	794	1522	−135	−352	−487	6·6	91·6
2	30	0¾	58·9	130	1907	2367	4274	1044	1221	2265	7·3	80·6
3	13	3	58·0	64	863	1146	2009	..	..	..	8·1	75·4
4	12	2¼	57·1	41	758	833	1591	−105	−313	−418	5·8	91·0
5A	12	3	58·0	68	806	909	1715	− 57	−237	−294	9·2	88·6
5B	12	2½	57·8	75	805	897	1702	− 58	−249	−307	10·3	89·7
6A	21	1¼	57·6	105	1333	1595	2928	470	449	919	8·6	83·6
6B	22	0	57·9	110	1383	1663	3046	520	517	1037	8·6	83·2
7A	27	0¾	58·4	150	1738	2269	4007	875	1123	1998	9·5	76·6
7B	26	0½	59·1	145	1690	2137	3827	827	991	1818	9·4	79·1
8A	32	2	59·1	166	2086	3169	5255	1223	2023	3246	8·7	65·9
8B	28	3¼	59·1	136	1837	2643	4480	974	1497	2471	8·0	69·5
9A	35	1¾	58·4	203	2271	3640	5911	1408	2494	3902	9·8	62·4
9B	22	3	58·5	95	1424	1817	3241	561	671	1232	7·1	78·4
10A	18	0¾	58·4	106	1168	1297	2465	305	151	456	10·0	90·0
10B	19	3	57·5	125	1259	1399	2658	396	253	649	11·0	90·0
11A	21	3¾	56·2	145	1378	1642	3020	515	496	1011	11·8	83·9
11B	21	0	56·4	170	1352	1552	2904	489	406	895	14·4	87·1
12A	25	2½	55·0	118	1525	1884	3409	662	738	1400	8·4	81·0
12B	21	3½	55·5	143	1352	1885	3237	489	739	1228	11·8	71·8
13A	28	2½	55·8	140	1737	2319	4056	874	1173	2047	8·8	74·9
13B	27	3½	55·3	157	1694	2220	3914	831	1074	1905	10·2	76·3
14A	28	2½	55·7	143	1737	2276	4013	874	1130	2004	8·9	76·3
14B	26	0¾	55·3	132	1580	2103	3683	717	957	1674	9·1	75·1
15A	25	2	55·9	109	1535	1917	3452	672	771	1443	7·7	80·1
15B	25	0½	55·9	100	1500	2025	3525	637	879	1516	7·2	74·1
16A	13	1¼	56·1	64	809	911	1720	− 54	−235	−289	8·6	88·9
16B	13	2½	55·1	47	799	953	1752	− 64	−198	−257	6·3	83·8
17A	13	3½	55·4	56	826	926	1752	− 37	−220	−257	7·3	89·1
17B	12	2	55·1	70	758	878	1636	−105	−268	−373	10·2	86·4
18A	31	1¾	55·7	151	1904	2533	4437	1041	1387	2428	8·6	75·1
18B	32	2	55·5	87	1892	2577	4469	1029	1431	2460	4·8	73·4
19	24	2¾	56·4	146	1538	1815	3353	675	669	1344	10·5	84·7
20–1	23	2	55·3	112	1410	1770	3180	547	624	1171	8·7	79·7
20–2	15	1½	56·4	55	921	1006	1927	58	−140	− 82	6·3	91·6
21	11	3½	54·6	60	709	715	1424	−154	−431	−585	9·3	99·1
22	10	3½	53·6	54	638	636	1274	−225	−510	−735	9·3	100·4

APPENDIX-TABLE XX.—PRODUCE of the 39th SEASON, 1881–2. SEED (SQUARE HEAD) SOWN OCTOBER 31, and NOVEMBER 1 and 2, 1881; CROP cut AUGUST 10–16, and carted AUGUST 24, 1882.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)						Increase per Acre by Manures.				
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).	Grain.	Straw and Chaff.	Total Produce.	Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Quantity.	Weight per Bushel.									
	bush. pks.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs		
0	13 0¾	61·0	44	846	1284	2130	167	189	356	5·5	65·9
1	9 1¾	60·1	36	605	1109	1714	−74	14	−60	6·2	54·5
2	32 2¾	59·6	57	2004	3993	5997	1325	2898	4223	2·9	50·2
3	10 3¾	58·7	38	679	1095	1774	..	..	..	5·9	62·0
4	10 3½	57·8	69	698	1017	1715	19	−78	−59	10·9	68·6
5A	12 3¾	58·4	37	793	1317	2110	114	222	336	4·9	60·2
5B	12 0	58·5	56	760	1244	2004	81	149	230	7·9	61·1
6A	23 1¼	60·7	48	1466	2897	4363	787	1802	2589	3·4	50·6
6B	22 3½	60·8	77	1468	2940	4408	789	1845	2634	5·6	49·9
7A	36 3½	60·2	89	2304	5819	8123	1625	4724	6349	4·1	39·6
7B	34 3	59·7	121	2198	5641	7839	1519	4546	6065	5·8	39·0
8A	36 0¾	59·2	162	2303	7413	9716	1624	6318	7942	7·6	31·1
8B	37 3¼	59·0	113	2343	6806	9149	1664	5711	7375	5·1	34·4
9A	31 3¼	59·8	108	2012	6274	8286	1333	5179	6512	5·7	32·1
9B	24 1¼	58·0	111	1520	3617	5137	841	2522	3363	7·9	42·0
10A	23 2¾	60·7	120	1557	2796	4353	878	1701	2579	8·3	55·7
10B	26 0¼	60·6	92	1672	3012	4684	993	1917	2910	5·8	55 5
11A	30 3¼	61·1	132	2015	3921	5936	1336	2826	4162	7·0	51·4
11B	29 3¼	61·2	126	1951	3805	5756	1272	2710	3982	6·9	51·3
12A	34 1¼	60·8	133	2221	4938	7159	1542	3843	5385	6·4	45·0
12B	34 3¾	61·2	81	2222	4636	6858	1543	3541	5084	3·8	47·9
13A	32 2¼	62·1	82	2105	4918	7023	1426	3823	5249	4·1	42·8
13B	31 3	61·5	96	2048	4865	6913	1369	3770	5139	4·9	42·1
14A	35 3¾	60·1	75	2235	4949	7184	1556	3854	5410	3·5	45·2
14B	33 1¾	60·5	110	2134	4570	6704	1455	3475	4930	5·4	46·7
15A	29 1¾	61·4	64	1871	4216	6087	1192	3121	4313	3·6	44·4
15B	28 1½	61·0	96	1827	3981	5808	1148	2886	4034	5·6	45·9
16A	11 0	58·4	55	698	1293	1991	19	198	217	8·5	54·0
16B	10 2¼	58·0	40	655	1204	1859	−24	109	85	6·6	54·4
17A	30 1	61·5	113	1971	4127	6098	1292	3032	4324	6·1	47·8
17B	31 3¼	61·7	59	2004	4186	6190	1325	3091	4416	3·0	47·9
18A	14 3¼	59·3	41	921	1497	2418	242	402	644	4·7	61·5
18B	16 1½	61·4	47	1052	1587	2639	373	492	865	4·7	66·3
19	30 1	61·7	82	1949	3458	5407	1270	2363	3633	4·4	56·4
20–1	18 1¼	61·3	80	1203	2045	3248	524	950	1474	7·1	58·8
20–2	15 2¼	61·3	40	993	1346	2339	314	251	565	4·2	73·7
21	15 1¼	60·5	54	979	1618	2597	300	523	823	5·8	60·4
22	11 2	60·2	33	725	1285	2010	46	190	236	4·7	56·4

APPENDIX-TABLE XXI.—PRODUCE of the 40th SEASON, 1882–3. SEED (SQUARE HEAD) sown NOVEMBER 6 and 9, 1882; CROP cut AUGUST 13–23, and carted AUGUST 24–27, 1883.

PLOTS.	Produce per Acre, &c. (For the Manures, see pp. 63 and 64.)							Increase per Acre by Manure.			Offal Grain to 100 Dressed.	Total Grain to 100 Straw.
	Dressed Grain.		Offal Grain.	Total Grain.	Straw and Chaff.	Total Produce (Grain and Straw).		Grain.	Straw and Chaff.	Total Produce.		
	Quantity.	Weight per Bushel.										
	bush. pks.	lbs.	lbs.	lbs.	lbs.	lbs.		lbs.	lbs.	lbs.		
0	15 0¾	61·7	43	980	997	1977		108	— 9	99	4·6	98·3
1	11 0½	61·6	25	712	783	1495		—160	—223	—383	3·7	90·9
2	35 0¾	62·4	49	2244	2930	5174		1372	1924	3296	2·2	76·6
3	13 3½	61·2	28	872	1006	1878		..	..	..	3·3	86·7
4	13 1¼	61·2	23	837	978	1815		— 35	— 28	— 63	2·9	85·6
5A	15 2	61·8	35	994	1101	2095		122	95	217	3·6	90·3
5B	15 3¼	62·0	37	1023	1175	2198		151	169	320	3·8	87·0
6A	27 2	62·1	50	1756	2655	4411		884	1649	2533	2·9	66·2
6B	27 3	63·4	50	1806	2554	4360		934	1548	2482	2·8	70·7
7A	35 3¼	62·7	107	2357	3657	6014		1485	2651	4136	4·8	64·4
7B	36 1¼	63·1	107	2399	3607	6006		1527	2601	4128	4·7	66·5
8A	43 0¾	63·4	137	2871	4654	7525		1999	3648	5647	5·0	61·7
8B	40 1¾	63·5	125	2695	3928	6623		1823	2922	4745	4·9	68·6
9A	43 1¼	62·1	218	2905	5127	8032		2033	4121	6154	7·9	56·7
9B	19 0¼	59·6	195	1337	1684	3021		465	678	1143	17·1	79·4
10A	17 2	60·4	141	1196	1419	2615		324	413	737	13·3	84·3
10B	18 1¾	61·0	162	1280	1524	2804		408	518	926	14·5	84·0
11A	27 3	61·7	129	1842	2466	4308		970	1460	2430	7·6	74·7
11B	25 0¼	60·6	106	1625	2158	3783		753	1152	1905	7·0	75·3
12A	31 1¼	63·1	131	2110	2854	4964		1238	1848	3086	6·6	73·9
12B	30 0¼	62·3	104	1977	2668	4645		1105	1662	2767	5·6	74·1
13A	34 1	63·7	115	2297	3504	5801		1425	2498	3923	5·3	65·6
13B	33 3¼	62·2	86	2196	3225	5421		1324	2219	3543	4·9	68·1
14A	34 0	62·3	144	2263	3128	5391		1391	2122	3513	6·8	72·3
14B	32 3	62·1	127	2162	2941	5103		1290	1935	3225	6·2	73·5
15A	33 0¼	62·7	124	2202	3227	5429		1330	2221	3551	6·0	68·2
15B	32 3¼	62·3	119	2164	3279	5443		1292	2273	3565	5·8	66·0
16A	15 1¼	62·8	44	1008	1063	2071		136	57	193	4·5	94·8
16B	16 1	62·1	37	1045	1146	2191		173	140	313	3·6	91·2
17A	15 2¾	62·4	55	1033	1153	2186		161	147	308	5·6	89·6
17B	15 2	62·3	34	999	1168	2167		127	162	289	3·5	85·5
18A	37 2¾	62·6	52	2411	3932	6343		1539	2926	4465	2·2	61·3
18B	38 3	62·5	48	2470	3766	6236		1598	2760	4358	2·0	65·6
19	30 2¼	62·7	63	1986	2759	4745		1114	1753	2867	3·3	72·0
20–1	31 0	62·0	135	2058	2887	4945		1186	1881	3067	7·0	71·3
20–2	17 0¼	61·2	54	1099	1110	2209		227	104	331	5·2	99·0
21	16 1	62·0	46	1054	1302	2356		182	296	478	4·6	80·9
22	12 2	62·4	35	816	887	1703		— 56	—119	—175	4·5	92·0

APPENDIX-TABLE XXII.—DRESSED GRAIN,

PLOTS.	HARVESTS.																			
	1864.		1865.		1866.		1867.		1868.		1869.		1870.		1871.		1872.		1873.		1874.		1875.	
	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.	bsh.	pks.
0	19	0	15	2	16	3	10	2½	22	1¼	15	1¼	21	2¾	13	3¾	17	1	15	2¼	16	3½	10	1¼
1	14	3¾	12	1½	11	1¾	7	3½	20	2¼	12	0¾	16	0¾	10	1½	10	3½	10	2	11	1½	8	0¼
2	40	0	37	0½	32	2½	27	2¼	41	3	38	1	36	2	38	3¾	32	1½	26	3	39	1	28	3¼
3	16	1¾	13	1¼	12	0½	8	3½	16	2½	14	1	14	3¾	9	1¼	10	2¾	11	2¾	11	1¾	8	2½
4	17	0¼	14	2¾	13	1½	9	1	17	2	14	3¼	15	2¾	10	1¼	11	1¼	12	0½	12	1	7	2¼
5A	16	1	14	0¾	13	0½	9	2½	16	1¼	15	2¼	18	0¾	11	0	12	3¾	12	3½	12	2¼	8	1
5B	17	2	14	0¾	13	1½	8	3½	18	3½	15	3½	19	0¾	12	3	12	2½	12	2	13	1¾	10	0¾
6A	31	1½	24	3¼	19	3½	15	1¼	27	3	21	0½	29	3	16	3¾	20	3¼	14	3¼	25	2¾	15	3¼
6B	30	3¼	25	0	21	0¼	16	0¾	28	3¾	22	0¼	31	0½	17	0	20	0¾	16	3¾	25	3½	16	3½
7A	44	1¼	40	0	30	0½	22	3¾	40	2	28	2¼	39	2¾	22	0¾	30	1¼	21	0½	39	1¼	25	0½
7B	47	1	40	1¾	29	3	21	1½	39	0¾	28	1	41	1½	22	1¼	29	0¼	22	3	39	2¼	26	2½
8A	49	3	43	3¼	32	0	29	1½	44	0½	35	0¼	45	3¾	26	1	37	0½	25	3¾	41	3½	31	0½
8B	50	0	43	1¼	32	1	31	1¾	48	3½	34	1¾	44	2	29	0½	34	0¼	29	0¼	39	0½	28	2¾
9A	51	0¼	44	0¼	32	2	29	0½	47	3¼	39	0	45	2	34	1¾	40	2¾	35	3¼	38	0¾	30	2
9B	33	1	29	2¼	30	3	22	0½	27	1	24	0½	26	1¾	17	2½	23	1½	21	3¼	21	2	16	2
10A	32	0¼	25	0¾	26	1	18	0½	24	3	20	1	21	2¾	10	0½	18	0	19	2½	25	1	12	3
10B	36	0¾	30	1¾	28	2	19	1½	27	2¾	19	0½	23	0¾	10	0	18	2¾	20	2½	27	0¾	14	2¼
11A	34	2	26	2¼	27	3½	21	3¾	33	1¾	24	0½	25	0½	12	0½	27	0	19	0½	36	2	19	3¾
11B	38	1½	28	0¼	28	0½	22	1	33	2½	20	1½	25	1¾	9	3½	27	1¾	19	1¾	29	1	15	3¾
12A	44	1¾	35	0¾	28	1½	25	0½	39	2	26	1¾	36	2	22	2¾	30	0	22	1¾	40	3¾	24	3¾
12B	44	3	33	3¾	28	0¾	23	3¾	40	1	28	0¼	34	0	19	1¾	28	2	23	1½	38	0	25	2¼
13A	42	2¾	35	3	24	0¾	23	1¾	37	3¼	25	2¾	35	2¼	28	1	30	1¼	22	3¾	36	3	26	0¾
13B	43	2¾	38	2	25	1¼	24	1	40	2¼	28	3¼	38	1½	2	0½	29	2	24	0	37	1¾	27	3¾
14A	41	0¼	36	0¼	28	1½	23	0¾	41	3¾	28	1	35	0½	2	2½	31	0¾	23	3¾	37	3¼	27	2¼
14B	41	3¾	37	0¼	27	2¼	22	1¼	41	1¾	27	0½	36	1	21	3¾	29	1¾	24	1	35	1½	25	0
15A	37	2¼	35	1¾	26	0	22	3½	44	0½	26	2½	38	0¾	29	1½	30	0¼	32	3¼	27	3	23	2¼
15B	37	1	36	1	26	1½	23	0½	41	2¼	27	0½	38	2½	32	0¼	32	1¼	32	1¼	30	2½	27	2
16A	50	3½	32	0	17	0½	14	1½	23	0	16	1¾	18	1¼	13	1	13	3½	12	2¼	9	0¼	10	2
16B	51	1½	32	2½	17	2	14	3¼	22	2¼	15	3¼	18	0¾	13	3	12	1¾	13	0	14	2½	9	3
2, 17A	36	2½	16	3½	27	0¾	10	3½	38	0¼	15	1	33	1½	13	1½	25	3	10	2½	32	3½	11	0¼
17B	35	3½	17	0¾	25	2½	10	2¾	36	3	17	0	35	1	18	2	26	0¼	12	3¼	33	2½	12	1
18A	17	0¼	30	0½	12	0¾	22	3	18	0¾	23	0¼	17	3	28	0¼	12	1¾	19	2	13	3	25	1
18B	18	1¼	32	3	13	0¾	24	1¾	19	0¾	22	3¼	20	1	28	3	13	1¾	21	0½	14	0½	25	3½
19	37	0½	32	3½	26	2¼	23	3¾	36	3¾	23	0¼	32	1	22	1¼	27	2¾	20	0	37	3¼	22	3½
20	13	2	13	2¾	13	2½	7	0¾	..	[5]	13	0¾	14	2¾	10	1¾	11	1½	12	2	13	3	8	0½
21	24	3½	18	1¼	17	2	12	2¼	26	1	20	2¼	25	3	15	0¾	20	3¼	14	0¼	22	3½	12	3¾
22	25	1½	19	0¾	18	1¾	12	2¾	24	3¾	15	0¾	26	2¼	16	3	20	0¼	18	0¼	21	1½	13	3

[1] Average of 9 years, 1865–73. See note (5) to Appendix-Table I., p. 64. [2] Average of 17A and 17B, are those of 10, 10 and 20 years mineral manure succeeding ammonia-salts ammonia-salts succeeding the mineral manure (Plots 17A and 17B, or 18A and 18B.) [5] Produce Appendix-Table I., p. 64. [7] Average of 9 years 1864–7 and 1869–73. [8] Average of 19 years

in Bushels and Pecks, per Acre, per Annum.

HARVESTS.									AVERAGE.			Plots.
1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	Of 10 Years, 1864–73.	Of 10 Years, 1874–83.	Of 20 Years, 1864–83.	
bsh. pks.	bsh. pks.	bsh. pks.	bsh. pks.	bsh. pks.	b-h. pks.	bsh. pks.	bsh. pks.	bush. pks.	bush. pks.	bush. pcks.	
11 3½	11 3¾	15 2	4 2¾	16 0¾	15 2½	13 0¾	15 0¾	16 3½	13 0½	14 3¾	0
7 2	7 0½	10 1½	2 2½	11 0	12 2¾	9 1¾	11 0½	12 3	9 0½	10 3¾	1
23 3½	24 0½	28 1	16 0	38 1½	30 0¾	32 2¾	35 0¾	35 0¾	29 2¾	32 1¾	2
8 0½	8 3½	12 1½	4 2¾	11 2	13 3	10 3¾	13 3½	12 3½	10 1¾	11 2½	3
9 0	9 3½	12 1¾	4 1¾	12 3	12 2½	10 3½	13 1½	13 2½	10 2	12 0¼	4
9 3¾	11 0¾	14 3	5 3	18 2½	12 3	12 3¾	15 2	14 0	12 0¾	13 0½	5A
11 0½	12 0½	14 2½	5 2½	16 3½	12 2½	12 0	15 3½	14 2½	12 1¾	13 2	5B
14 3¼	14 2¾	22 1	9 1½	27 3	21 1½	23 1¼	27 2	22 1	20 1	21 1	6A
16 2	14 1½	23 0¾	11 2¾	26 0½	22 0	22 3½	27 3	22 3¾	20 2¾	21 3½	6B
21 1¾	20 2½	30 1½	15 1	34 2½	27 0¾	36 3¼	35 3½	31 3¾	28 2¾	30 1½	7A
25 2	19 0½	32 0¾	17 1	34 1½	26 0½	34 3	36 1½	32 0¾	29 0¾	30 2¾	7B
30 2¾	27 0¾	37 3½	20 0½	37 2¾	32 2	36 0¾	43 0¾	36 3¾	33 3½	35 1½	8A
28 2	22 1	38 1½	21 0	32 3½	28 3¼	37 3¼	40 1¾	37 2¾	31 3½	34 3	8B
33 1½	40 0½	37 0¾	21 3¾	34 0½	35 1¾	31 3¼	43 1½	40 0	34 2½	37 1¼	9A
13 0	27 2¾	23 1½	4 2½	10 1¾	22 3	24 1½	19 0½	25 2½	18 1¼	22 0	9B
12 0½	17 0¾	27 1½	3 3¾	10 2½	18 0¾	23 2¾	17 2	21 2½	16 3½	19 1	10A
14 1¾	18 1	29 3½	4 2½	13 1¾	19 3	26 0½	18 1½	23 1½	18 2½	21 0	10B
15 1	18 3¾	29 2½	11 0¾	27 0½	21 3¾	30 3½	27 3	25 0¾	23 3¾	24 2½	11A
13 1¾	16 3½	29 2½	11 0½	24 2	21 0	29 3½	25 0½	25 1½	21 2½	23 2	11B
19 2½	19 3½	28 3	13 3½	30 3	25 2½	34 1½	31 1½	31 0½	27 0	29 0	12A
18 3	15 3	29 2½	14 1	27 3¾	21 3½	34 3¾	30 0½	30 1¾	25 2¾	28 0½	12B
24 2	18 2	29 0	14 0¾	33 0½	28 2¾	32 2½	34 1	30 2¾	27 3½	29 0¾	13A
25 3½	18 0	29 3¾	17 3¾	32 3½	27 3¾	31 3	33 3½	32 2	28 1½	30 1¾	13B
22 3½	19 0½	32 2	16 3	32 1	28 2½	35 3¾	34 0	31 2½	28 3	30 0½	14A
21 1	18 0	31 2½	15 2¾	29 2¾	26 0¾	33 1¾	32 3	30 3¾	26 3½	28 3¾	14B
24 3	32 3½	20 3¾	5 3¼	36 3½	25 2	29 1¾	33 0½	32 1½	26 0½	29 0¾	15A
26 0½	33 1¾	23 0¾	4 3¾	35 1¾	25 0½	28 1½	32 3½	32 2¾	26 3	29 3	15B
10 3¾	10 1	13 3¾	5 1½	14 2½	13 1½	11 0	15 1½	17 3½	11 1¾	14 2	16A
11 0½	9 1½	13 0¾	4 1½	14 0¾	13 2½	10 2½	16 1	17 3½	11 2¾	14 2½	16B
27 0	10 0½	29 1½	2 2¾	32 0	13 3½	30 1	15 2¾	14 1¾	12 0¾	13 1½	17A
25 3½	9 3½	28 2½	3 2¾	33 2½	12 2	31 3½	15 2	16 0½	12 2½	14 1½	17B
10 0½	11 2¾	15 0½	19 3½	14 2½	31 1¾	14 3½	37 2¾	28 1¾	27 3	28 0½	18A
10 2½	13 2	15 1½	20 3¾	15 1½	32 2	16 1½	38 3	28 3¾	28 2	28 3	18B
19 1	19 1¾	27 1¾	8 0¾	32 2	24 2¾	30 1	30 2½	28 1¼	25 1¼	26 3¼	19
7 1½	11 1½	14 1	4 1	20 3¼	23 2	18 1½	31 0	..	..	23 1¾ [6]	20–1
				12 3	15 1½	15 2½	17 0½	12 1 [7]	12 0	12 0¾ [6]	20–2
10 3	11 2½	19 1½	8 1½	16 2	11 3½	15 1½	16 1	19 2¼	14 2½	17 0½	21
13 0¾	21 0½	18 2¾	11 3¼	26 1¾	10 3½	11 2	12 2	19 3	16 0½	17 3¾	22

19 years, 1865–83. [5] See Note (6) to Appendix-Table I., p. 64. [6] The averages given for Plots (Plots 17A and 17B, or 18A and 18B); and those given for Plots 18A and 18B of 10, 10 and 20 years unknown, owing to a mistake at harvest. [7] Average of 4 years, 1880–83. See Note (5) to 1864–7 and 1869–83.

APPENDIX-TABLE XXIII.—WEIGHTS per BUSHEL.

PLOTS.	HARVESTS.											
	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	62·0	59·0	60·0	58·7	61·4	58·1	62·1	56·5	58·7	57·6	59·1	59·4
1	62·0	59·0	59·8	57·9	60·0	58·2	62·5	57·0	57·9	56·6	59·6	58·5
2	62·5	61·5	61·7	61·4	61·6	56·9	63·4	60·0	60·7	58·1	60·2	60·6
3	62·0	60·6	61·3	56·1	61·0	56·1	61·8	54·8	59·0	57·0	58·3	60·0
4	61·9	60·3	60·9	58·6	61·6	57·1	62·6	57·0	57·6	57·2	58·8	59·7
5A	62·1	61·0	60·8	59·7	62·2	56·8	62·6	56·4	60·2	56·8	59·1	59·2
5B	62·0	60·8	61·0	59·0	63·5	57·0	62·6	56·7	59.8	57·0	59·1	59·5
6A	62·0	61·0	61·0	60·6	62·4	57·0	63·0	56·8	60·1	57·5	59·7	60·7
6B	62·0	60·9	61·0	60·5	63·2	57·3	63·1	56·3	60·3	56·6	59·5	59·8
7A	63·0	61·6	61·1	61·3	61·5	57·7	63·3	56·0	60·4	57·0	59·9	59·9
7B	63·1	61·7	60·9	60·7	60·6	57·2	63·2	57·3	60·0	57·3	59·7	59·0
8A	63·5	61·3	60·0	60·8	62·1	57·0	63·7	57·1	60·5	57·5	60·1	58·2
8B	63·5	61·5	60·2	60·5	61·9	57·5	63·8	58·3	60·4	56·3	59·6	58·1
9A	62·6	61·1	60·6	59·9	61·1	57·1	62·7	58·6	60·0	57·1	60·4	57·9
9B	61·7	59·5	59·9	57·4	62·0	54·6	61·8	52·4	55·5	54·9	57·5	55·7
10A	61·8	59·6	61·2	57·9	61·9	54·9	60·8	53·8	56·8	56·1	56·5	54·5
10B	62·1	59·8	61·5	59·3	62·4	55·6	60·8	53·8	55·9	56·5	56·9	55·6
11A	59·7	57·2	60·8	59·1	62·4	56·2	60·8	54·3	59·5	56·0	57·9	55·5
11B	59·0	57·3	60·5	59·8	62·2	55·1	60·7	53·8	58·6	55·1	58·3	54·6
12A	62·6	60·0	61·0	60·2	63·6	58·1	62·4	56·5	60·1	56·9	59·4	58·1
12B	62·4	60·3	61·3	60·6	63·3	57·9	62·5	55·6	59·4	56·5	59·7	57·2
13A	63·2	61·1	62·0	60·8	63·0	59·3	63·7	57·6	60·3	57·4	60·6	60·4
13B	63·4	61·1	61·5	60·7	63·2	59·0	63·9	58·2	60·8	57·3	60·4	60·0
14A	63·1	60·3	61·1	59·8	63·9	58·5	63·2	57·0	59·8	57·0	59·9	59·0
14B	62·8	60·4	61·3	59·6	64·1	58·1	62·7	56·7	59·5	56·6	59·2	58·0
15A	63·1	60·9	61·6	60·2	63·8	58·1	63·8	59·0	60·5	57·7	61·3	59·9
15B	63·0	61·6	61·4	59·5	63·3	59·3	63·9	58·7	60·7	57·9	60·9	60·6
16A	63·2	61·8	61·9	59 4	62·9	58·6	63·2	57·2	59·5	57·4	60·2	59·8
16B	63·2	61·7	61·6	59·1	62·7	58·1	63·3	56·5	59·3	57·0	60·0	59·5
(3) 17A	62·6	60·9	61·3	59·2	63·4	58·1	63·6	56·0	60·8	56·6	60·6	58·9
(3) 17B	62·6	60·6	61·1	57·6	64·2	57·3	63·7	56·8	60·5	57·6	60·9	59·6
(3) 18A	61·3	60·1	60·6	59·1	62·7	58·7	63·1	58·6	59·3	57·3	58·8	59·2
(3) 18B	61·6	60·3	60·8	57·5	62·9	58·0	63·3	58·0	59·5	57·6	58·8	58·9
19	62·3	58·9	59·7	56·7	62·9	56·7	62·3	56·0	59·6	56·7	58·9	56·5
20	63·3	60·2	59·1	56·4	~~62·0~~ 5	56·9	62·5	55·8	57·1	56·9	59·2	57·0
21	62·3	58·0	59·9	59·3	62·6	58·1	63·1	56·8	59·6	56·9	59·5	59·9
22	62·0	58·3	59·8	59·3	62·8	58·1	63·0	56·9	59·8	56·9	59·3	60·2

[1] Average of 9 years, 1865–73. See Note (*) to Appendix-Table I., p. 64. [2] Average of 17B, are those of 10, 10 and 20 years mineral manure succeeding ammonia-salts (Plots 17A and succeeding the mineral manure (Plots 17A and 17B, or 18A and 18B). [3] Produce unknown, p. 64. [4] Average of 9 years 1864–7 and 1869–73. [5] Average of 19 years 1864–7 and 1869–83.

of Dressed Grain; each Year.

HARVESTS.								AVERAGE.			Plots.
1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	Of 10 Years, 1864–73.	Of 10 Years, 1874–83.	Of 20 Years, 1864–83.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
57·3	59·0	59·0	54·0	58·6	54·2	61·0	61·7	59·4	58·3	58·9	0
56·8	59·3	59·1	54·0	57·6	53·7	60·1	61·6	59·1	58·0	58·6	1
62·4	59·1	60·9	56·8	60·2	58·9	59·6	62·4	60·8	60·1	60·5	2
59·0	58·9	59·0	52·5	56·9	58·0	58·7	61·2	59·0	58·3	58·6	3
58·5	57·3	59·9	51·1	57·4	57·1	57·8	61·2	59·5	57·9	58·7	4
59·2	57·4	58·3	53·9	59·1	58·0	58·4	61·8	59·9	58·4	59·2	5A
59·1	56·8	59·3	53·0	59·2	57·8	58·5	62·0	59·9	58·4	59·2	5B
61·9	59·6	61·1	56·2	59·8	57·6	60·7	62·1	60·1	59·9	60·0	6A
62·2	56·7	60·5	56·7	59·8	57·9	60·8	63·4	60·1	59·7	59·9	6B
63·2	59·1	60·6	56·5	59·7	58·4	60·2	62·7	60·3	60·0	60·2	7A
62·7	59·3	60·6	56·8	59·9	59·1	59·7	63·1	60·2	60·0	60·1	7B
63·1	59·4	60·4	56·7	59·6	59·1	59·2	63·4	60·4	59·9	60·2	8A
62·7	59·0	60·2	56·2	58·5	59·1	59·0	63·5	60·4	59·6	60·0	8B
62·7	57·9	59·2	56·5	57·8	58·4	59·8	62·1	60·1	59·3	59·7	9A
56·3	58·0	56·9	49·8	53·5	58·5	58·0	59·6	57·9	56·4	57·2	9B
57·2	57·5	59·5	48·9	54·9	58·4	60·7	60·4	58·5	56·9	57·7	10A
56·4	58·4	59·6	52·6	53·5	57·5	60·6	61·0	58·8	57·2	58·0	10B
59·6	60·0	59·9	55·5	58·4	56·2	61·1	61·7	58·6	58·6	58·6	11A
58·4	59·8	60·0	53·6	57·3	56·4	61·2	60·6	58·2	58·0	58·1	11B
61·0	60·2	60·5	56·4	59·2	55·0	60·8	63·1	60·1	59·4	59·8	12A
60·4	59·9	60·8	55·3	58·7	55·5	61·2	62·3	60·0	59·1	59·6	12B
62·1	60·1	61·1	57·5	59·9	55·8	62·1	63·7	60·8	60·3	60·6	13A
62·4	60·1	60·6	58·0	59·4	55·3	61·5	62·2	60·9	60·0	60·5	13B
61·4	59·5	60·8	57·7	59·2	55·7	60·1	62·3	60·4	59·6	60·0	14A
60·7	57·2	60·3	56·6	57·8	55·3	60·5	62·1	60·2	58·8	59·5	14B
62·3	58·9	59·6	53·1	60·8	55·9	61·4	62·7	60·9	59·6	60·3	15A
61·7	59·6	60·1	52·5	60·7	55·9	61·0	62·3	60·9	59·5	60·2	15B
58·5	57·2	59·3	52·8	58·1	56·1	58·4	62·8	60·2 [1]	58·3	59·2 [2]	16A
58·4	58·9	60·3	52·9	58·5	55·1	58·0	62·1	59·9 [1]	58·4	59·1 [2]	16B
61·1	59·1	61·0	52·5	60·7	55·4	61·5	62·4	59·8 [4]	58·3 [4]	59·0 [4]	17A [3]
60·6	58·6	60·8	49·5	59·5	55·1	61·7	62·3	59·8 [4]	58·2 [4]	59·0 [4]	17B [3]
58·3	58·0	59·8	58·7	58·1	55·7	59·3	62·6	60·6 [4]	59·9 [4]	60·2 [4]	18A [3]
58·5	58·8	60·2	57·9	57·7	55·5	61·4	62·5	60·4 [4]	59·7 [4]	60·0 [4]	18B [3]
57·6	58·0	60·0	53·6	58·4	56·4	61·7	62·7	59·2	58·4	58·8	19
57·3	58·1	57·7	53·0	60·0 [5]	55·3	61·3	62·0	..	..	59·7 [6]	20–1
				56·6 [5]	56·4	61·3	61·2	58·7 [7]	57·8	58·2 [6]	20–2
57·4	58·5	59·3	54·0	57·3	54·6	60·5	62·0	59·7	58·3	59·0	21
57·0	55·0	59·0	55·5	57·3	53·6	60·2	62·4	59·7	58·0	58·9	22

19 years, 1865–83. [2] See Note to Appendix-Table I., p. 64. [4] The averages given for Plots 17A and 17B, or 18A and 18B); and those given for Plots 18A and 18B of 10, 10 and 20 years ammonia-salts owing to a mistake at harvest. [6] Average of 4 years, 1880–83. See Note (*) to Appendix-Table I.,

APPENDIX-TABLE XXIV.—TOTAL GRAIN

PLOTS.	HARVESTS.											
	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	1241	993	1033	664	1404	955	1415	889	1060	950	1014	663
1	962	802	709	487	1259	744	1056	685	701	636	690	511
2	2595	2384	2070	1755	2604	2256	2359	2498	2046	1622	2481	1890
3	1078	828	777	532	1054	848	956	615	705	701	694	567
4	1085	950	852	583	1103	896	1023	708	717	749	734	508
5A	1052	910	832	609	1044	928	1178	718	836	771	768	526
5B	1121	920	843	551	1226	956	1228	827	833	754	820	653
6A	2016	1589	1255	972	1782	1273	1936	1099	1308	905	1550	1046
6B	1978	1621	1333	1033	1887	1345	2023	1078	1299	1015	1562	1084
7A	2912	2550	1897	1469	2528	1748	2568	1503	1936	1264	2436	1652
7B	3087	2609	1885	1365	2408	1771	2672	1520	1937	1381	2461	1723
8A	3284	2809	2057	1896	2794	2105	2992	1745	2404	1566	2637	2006
8B	3300	2857	2051	2008	3069	2086	2939	1940	2244	1720	2471	1867
9A	3330	2881	2061	1855	2970	2368	2940	2228	2565	2160	2409	1965
9B	2182	2005	1979	1392	1799	1452	1735	1093	1434	1303	1269	1050
10A	2093	1649	1693	1123	1627	1210	1420	675	1178	1173	1476	786
10B	2395	1938	1848	1237	1846	1188	1496	663	1166	1247	1686	934
11A	2210	1696	1789	1360	2211	1443	1653	795	1766	1153	2208	1217
11B	2394	1780	1800	1416	2207	1251	1682	668	1758	1152	1859	1026
12A	2881	2277	1804	1577	2611	1638	2347	1458	1928	1360	2497	1585
12B	2882	2220	1812	1511	2620	1726	2218	1259	1824	1401	2359	1574
13A	2785	2328	1576	1471	2417	1631	2328	1812	1946	1395	2303	1673
13B	2882	2506	1647	1529	2614	1827	2535	2050	1923	1440	2301	1766
14A	2740	2345	1813	1450	2716	1778	2336	1728	1995	1426	2294	1747
14B	2745	2390	1768	1898	2754	1701	2398	1490	1897	1452	2187	1576
15A	2459	2291	1655	1427	2856	1635	2502	1905	1961	1963	1724	1594
15B	2421	2411	1690	1435	2692	1694	2550	2093	2095	1941	1901	1829
16A	3333	2113	1111	890	1481	1019	1207	836	874	759	564	676
16B	3370	2125	1127	907	1438	982	1208	841	791	778	915	613
17A	2378	1097	1739	678	2466	952	2187	824	1685	639	2027	691
17B	2316	1098	1643	658	2413	1059	2315	1129	1673	789	2094	777
18A	1078	1916	775	1384	1168	1431	1175	1763	818	1177	832	1569
18B	1169	2065	846	1448	1239	1418	1335	1792	862	1274	871	1598
19	2440	2083	1698	1421	2422	1447	2137	1413	1794	1212	2293	1392
20	929	889	837	433	.. [6]	826	943	665	696	758	845	501
21	1625	1128	1072	787	1687	1260	1666	979	1312	853	1391	842
22	1642	1195	1123	791	1615	942	1723	1067	1257	1084	1289	893

[1] Average of 9 years, 1865–73. See Note (4) to Appendix-Table I., p. 64. [2] Average of and 17B, are those of 10, 10 and 20 years, mineral manure succeeding ammonia-salts (Plots 17A succeeding the mineral manure (Plots 17A and 17B, or 18A and 18B). [5] Produce unknown, p. 64. [7] Average of 9 years 1864–7 and 1869–73. [8] Average of 19 years 1864–7 and 1869–83.

in lbs., per ACRE, per ANNUM.

HARVESTS.								AVERAGE.			PLOTS.
1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	Of 10 Years, 1864–73.	Of 10 Years, 1874–83.	Of 20 Years, 1864–83.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
733	728	959	318	990	909	846	980	1060	814	937	0
440	434	654	182	655	728	605	712	804	561	683	1
1545	1481	1890	1064	2373	1907	2004	2244	2219	1883	2051	2
500	543	776	330	689	863	679	872	809	651	730	3
546	584	776	317	760	758	698	837	866	652	759	4
610	668	899	385	1128	806	793	994	888	758	823	5A
679	708	901	382	1038	805	760	1023	926	777	851	5B
962	904	1424	619	1718	1333	1466	1756	1413	1278	1346	6A
1081	847	1468	762	1610	1383	1468	1806	1461	1307	1384	6B
1444	1259	1998	969	2149	1738	2304	2357	2037	1831	1934	7A
1719	1167	2132	1133	2149	1690	2198	2399	2064	1877	1970	7B
2054	1665	2452	1318	2374	2086	2303	2871	2365	2177	2271	8A
1895	1354	2485	1384	2031	1837	2343	2695	2421	2036	2229	8B
2255	2383	2333	1462	2130	2271	2012	2905	2536	2212	2374	9A
766	1654	1408	345	654	1424	1520	1337	1637	1143	1390	9B
719	1031	1708	272	645	1168	1557	1196	1384	1056	1220	10A
848	1105	1853	370	779	1259	1672	1280	1502	1179	1340	10B
963	1182	1894	788	1673	1378	2015	1842	1607	1516	1562	11A
832	1046	1903	676	1520	1352	1951	1625	1611	1379	1495	11B
1280	1249	1906	913	1921	1525	2221	2110	1988	1719	1853	12A
1206	994	1966	952	1739	1352	2222	1977	1947	1634	1791	12B
1575	1165	1888	964	2070	1737	2105	2297	1969	1777	1873	13A
1669	1108	1917	1188	2029	1694	2048	2196	2095	1792	1943	13B
1454	1170	2085	1105	2007	1737	2235	2263	2032	1810	1921	14A
1338	1063	1994	1089	1811	1580	2134	2162	1999	1693	1846	14B
1602	1978	1334	406	2325	1535	1871	2202	2065	1657	1861	15A
1709	2036	1495	333	2242	1500	1827	2164	2102	1704	1903	15B
658	610	862	359	882	809	698	1008	1143 [1]	713	917 [2]	16A
669	567	837	321	885	799	655	1045	1133 [1]	731	921 [2]	16B
1709	662	1914	189	2017	826	1971	1033	920 [4]	762 [4]	841 [4]	17A [3]
1611	591	1834	255	2083	758	2004	999	1018 [4]	785 [4]	902 [4]	17B [3]
609	696	955	1284	903	1904	921	2411	1813 [4]	1750 [4]	1781 [4]	18A [3]
639	816	976	1330	935	1892	1052	2470	1835 [4]	1773 [4]	1804 [4]	18B [3]
1147	1156	1723	573	2057	1538	1949	1986	1807	1581	1694	19
442	694	863	296	1314	1410	1203	2058	.. [7]	..	1496 [6]	20–1
				771	921	993	1099	775 [7]	742	758 [8]	20–2
681	710	1208	541	992	709	979	1054	1237	910	1074	21
817	1197	1163	761	1581	638	725	816	1244	988	1116	22

19 years, 1865–83. [2] See Note (*) to Appendix-Table I., p. 64. [4] The averages given for Plots 17A and 17B, or 18A and 18B); and those given for Plots 18A and 18B, of 10, 10, and 20 years, ammonia-salts owing to a mistake at harvest. [6] Average of 4 years, 1880–83. See Note (*) to Appendix-Table I.,

APPENDIX-TABLE XXV.—TOTAL STRAW (and

PLOTS.	HARVESTS.											
	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	1575	1135	1729	1320	1855	1493	1239	1566	1878	1183	1328	1150
1	1296	1064	1301	944	1594	1180	1087	1451	1270	966	972	868
2	3893	3100	4058	3136	4190	3937	2733	4506	3761	2463	4489	3719
3	1350	1033	1269	973	973	1350	1046	1100	1152	902	990	1008
4	1337	1162	1419	999	1345	1405	1107	1277	1216	998	999	910
5A	1293	1132	1454	1099	1250	1514	1302	1340	1301	1054	845	1051
5B	1458	1220	1476	966	1442	1687	1419	1529	1361	1032	914	1198
6A	3630	1978	2207	1684	2437	2250	2269	2290	2770	1513	2212	1899
6B	3127	2063	2289	1762	2700	2280	2438	2304	2363	1527	2230	2117
7A	4897	3598	3844	2796	4017	3114	3148	3093	3611	1852	4508	3334
7B	5043	3740	3923	2727	3680	3309	3284	3076	4043	2190	4782	3509
8A	5585	4517	5318	4103	4683	3898	3635	3716	5430	2477	6182	4400
8B	5590	4682	5306	4288	4933	3937	3699	4150	4712	2850	5944	4245
9A	5985	4682	5316	4918	5180	4930	3911	4909	6527	3932	5012	4747
9B	3287	3137	4682	3246	2742	3475	2080	2425	3210	2358	2166	2363
10A	2832	2385	2792	2023	2163	2265	1627	1252	2442	1635	1977	1574
10B	3247	2677	3047	2138	2364	2186	1748	1339	2440	1642	2387	1782
11A	3440	2397	3130	2218	2790	2568	1917	1448	3387	1583	3166	2392
11B	3878	2662	3252	2402	2850	2345	1895	1279	3450	1578	3077	2217
12A	4315	3067	3473	2628	3421	2637	2577	2700	3933	1943	4011	2972
12B	4356	3148	3538	2685	3653	3008	2503	2440	3388	2037	3774	3104
13A	4480	3243	3350	2662	4010	2826	2815	3433	3988	2036	3952	3299
13B	4620	3518	3623	2822	4040	3267	2993	4125	3808	2107	4002	3231
14A	4003	3127	3563	2598	3685	3076	2584	3063	3850	2120	3570	3060
14B	4107	3195	3367	2537	3668	2999	2588	2937	3725	2172	3618	3183
15A	4003	3142	3053	2670	4656	2954	3072	3597	4011	2992	2609	2916
15B	4010	3875	3297	2730	4223	3008	3119	3808	4134	3165	2943	3491
16A	6003	2837	1955	1583	2125	1678	1365	1510	1642	1130	913	1222
16B	5990	2938	1968	1643	1962	1614	1333	1573	1466	1174	1392	1147
17A	3920	1488	3365	1193	3767	1570	2628	1608	3249	1092	3501	1247
17B	3667	1452	3582	1257	3527	1829	2715	2032	3358	1108	3473	1450
18A	1460	2785	1502	2558	1537	2433	1259	3254	1579	1805	1047	2916
18B	1600	2877	1533	2675	1672	2460	1488	3428	1761	2007	1012	3096
19	3363	2987	3347	2620	3161	2566	2242	2688	3303	1858	3136	2494
20	1332	1307	1627	948	.. [5]	1253	1175	1350	1247	1098	1312	1028
21	2323	1458	2104	1388	2267	2115	1949	1873	2216	1258	1666	1376
22	2180	1527	2127	1377	2300	1483	1996	1871	2030	1663	1547	1491

[1] Average of 9 years, 1865–73. See Note (*) to Appendix-Table I., p. 64. [2] Average of and 17B, are those of 10, 10 and 20 years, mineral manure succeeding ammonia-salts (Plots 17A succeeding the mineral manure (Plots 17A and 17B, or 18A and 18B). [5] Produce unknown, p. 64. [7] Average of 9 years 1864–7 and 1869–73. [8] Average of 19 years 1864–7 and 1869–83.

CHAFF), in lbs., per ACRE, per ANNUM.

HARVESTS.								AVERAGE.			PLOTS.
1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	Of 10 Years, 1864–73.	Of 10 Years, 1874–83.	Of 20 Years, 1864–83.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
830	908	1420	691	1315	973	1284	997	1497	1090	1293	0
571	521	1064	428	1151	794	1109	783	1215	826	1020	1
2140	2266	4042	2239	3902	2367	3993	2930	3578	3203	3391	2
642	748	1081	763	1149	1146	1095	1006	1115	963	1039	3
706	807	992	748	1263	833	1017	978	1227	925	1076	4
792	872	1324	841	1747	909	1317	1101	1274	1080	1177	5A
777	892	1320	868	1722	897	1244	1175	1359	1101	1230	5B
1201	1172	2813	1400	3172	1595	2897	2655	2303	2101	2202	6A
1393	1179	3074	1784	2649	1663	2940	2554	2285	2158	2222	6B
2015	1983	4804	2890	4051	2269	5819	3657	3397	3533	3465	7A
2408	1687	5100	3133	3960	2137	5641	3607	3501	3596	3549	7B
3083	2477	6227	4069	5135	3169	7413	4654	4336	4681	4508	8A
2788	2010	6119	4283	3817	2643	6806	3928	4415	4258	4336	8B
3584	3852	5624	4347	4394	3640	6274	5127	5029	4660	4845	9A
1217	2540	2897	1070	1420	1817	3617	1684	3064	2079	2572	9B
922	1322	2762	889	1242	1297	2796	1419	2142	1620	1881	10A
1270	1492	2981	1006	1631	1399	3012	1524	2283	1848	2066	10B
1313	1453	4258	2086	2868	1642	3921	2466	2488	2556	2522	11A
1228	1353	4326	1955	2835	1552	3805	2158	2559	2451	2505	11B
1711	1640	4479	2555	3589	1884	4938	2854	3069	3063	3066	12A
1661	1331	4824	2384	2939	1885	4636	2668	3076	2921	2998	12B
2431	1581	4708	2776	3859	2319	4918	3504	3284	3335	3310	13A
2435	1556	4664	3327	3649	2220	4865	3225	3492	3317	3405	13B
2027	1633	5014	3072	3638	2276	4949	3128	3167	3236	3202	14A
1863	1503	4794	2734	3009	2103	4570	2941	3130	3032	3081	14B
2320	2817	2931	1019	4234	1917	4216	3227	3415	2821	3118	15A
2535	2759	3211	792	3816	2025	3981	3279	3487	2883	3185	15B
841	736	1351	808	1736	911	1293	1063	1758 [1]	1087	1405 [2]	16A
908	767	1312	819	1263	953	1204	1146	1741	1091	1399	16B
2605	823	4528	589	3383	926	4127	1153	1429 [4]	1103 [4]	1266 [4]	17A
2474	728	4735	659	3271	878	4186	1168	1573	1132	1353	17B
898	1038	1514	3283	1340	2533	1497	3932	2976 [4]	3185 [4]	3081 [4]	18A
893	1090	1596	3406	1351	2577	1587	3766	3030	3208	3119	18B
1566	1452	3148	1335	3254	1815	3458	2759	2813	2442	2628	19
665	994	1212	745	2120 / 1096	1770 / 1006	2045 / 1346	2887 / 1110	.. [7]	..	2206 [6] / 1150 [8]	20–1 / 20–2
								1260	1052		
935	1049	1821	1138	1626	715	1618	1302	1895	1325	1610	21
1214	1725	1880	1798	2469	636	1285	887	1855	1493	1674	22

19 years, 1865–83. [2] See Note (*) to Appendix-Table I., p. 64. [4] The averages given for Plots 17 and 17B, or 18A and 18B), and those given for Plots 18A and 18B of 10, 10 and 20 years ammonia-sal owing to a mistake at harvest. [6] Average of 4 years 1880–83. See Note (*) to Appendix-Table I

APPENDIX-TABLE XXVI.—TOTAL PRODUCE (GRAIN

PLOTS.	HARVESTS.											
	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	1872.	1873.	1874.	1875.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
0	2816	2128	2762	1984	3259	2448	2654	2455	2933	2133	2342	1813
1	2258	1866	2010	1431	2853	1924	2143	2136	1971	1602	1662	1379
2	6488	5484	6128	4891	6794	6193	5092	7004	5807	4085	6870	5609
3	2428	1861	2046	1505	2027	2198	2002	1715	1857	1603	1684	1575
4	2422	2112	2271	1582	2448	2301	2130	1985	1933	1747	1733	1418
5A	2345	2042	2286	1708	2294	2442	2480	2058	2137	1825	1613	1577
5B	2579	2140	2319	1517	2668	2643	2647	2356	2194	1786	1734	1851
6A	5646	3567	3462	2656	4219	3523	4205	3389	4078	2418	3762	2945
6B	5105	3684	3622	2795	4587	3625	4461	3382	3662	2542	3792	3201
7A	7809	6148	5741	4265	6545	4862	5716	4596	5547	3116	6944	4986
7B	8130	6349	5808	4092	6088	5080	5956	4596	5980	3571	7243	5232
8A	8869	7326	7375	5999	7477	6003	6627	5461	7834	4043	8819	6406
8B	8890	7539	7357	6296	8002	6023	6638	6090	6956	4570	8415	6112
9A	9315	7563	7377	6773	8150	7298	6851	7137	9092	6092	7421	6712
9B	5469	5142	6661	4638	4541	4927	3815	3518	4644	3661	3435	3413
10A	4925	4084	4485	3146	3790	3475	3047	1927	3620	2808	3453	2360
10B	5642	4615	4895	3375	4210	3374	3244	2002	3606	2889	4073	2716
11A	5650	4093	4919	3578	5001	4011	3570	2243	5153	2736	5374	3609
11B	6272	4442	5052	3818	5057	3596	3577	1947	5208	2730	4936	3243
12A	7196	5344	5277	4205	6032	4275	4924	4158	5861	3303	6508	4557
12B	7238	5368	5350	4196	6273	4734	4721	3699	5212	3438	6133	4678
13A	7265	5571	4926	4133	6427	4457	5143	5245	5934	3431	6255	4972
13B	7502	6024	5270	4351	6654	5094	5528	6175	5731	3547	6303	4997
14A	6743	5472	5376	4048	6401	4854	4920	4791	5845	3546	5864	4807
14B	6852	5585	5135	3935	6422	4700	4986	4427	5622	3624	5805	4759
15A	6462	5433	4708	4097	7512	4589	5574	5502	5972	4955	4333	4510
15B	6431	5786	4987	4165	6915	4702	5669	5901	6229	5106	4844	5320
16A	9336	4950	3066	2473	3606	2697	2572	2346	2516	1889	1477	1898
16B	9360	5063	3095	2550	3400	2596	2541	2414	2257	1952	2307	1760
[1] 17A	6298	2585	5104	1871	6233	2522	4815	2432	4934	1731	5528	1938
[1] 17B	5983	2550	5225	1915	5940	2888	5030	3161	5031	1897	5567	2227
[1] 18A	2538	4701	2277	3942	2705	3864	2434	5017	2397	2982	1879	4485
[1] 18B	2769	4942	2379	4123	2911	3878	2823	5220	2623	3281	1883	4694
19	5803	5070	5045	4041	5583	4013	4379	4101	5097	3070	5429	3886
20	2261	2196	2464	1381	.. [5]	2079	2118	2015	1943	1856	2157	1529
21	3948	2586	3176	2175	3954	3375	3615	2852	3528	2111	3057	2218
22	3822	2722	3250	2168	3915	2425	3719	2938	3287	2747	2836	2384

[1] Average of 9 years, 1865–73. See Note (5) to Appendix-Table I, p. 64. [2] Average of and 17B, are those of 10, 10 and 20 years mineral manure succeeding ammonia-salts (Plots 17A succeeding the mineral manures (Plots 17A and 17B or 18A and 18B). [5] Produce unknown, p. 64. [7] Average of 9 years 1864–7 and 1869–73. [8] Average of 19 years 1864–7 and 1869–83,

nd Straw), in lbs., per Acre, per Annum.

HARVESTS.								AVERAGE.			Plots.
1876.	1877.	1878.	1879.	1880.	1881.	1882.	1883.	Of 10 Years, 1864–73.	Of 10 Years, 1874–83.	Of 20 Years, 1864–83.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1563	1636	2379	1009	2305	1882	2130	1977	2557	1904	2230	0
1011	955	1718	610	1806	1522	1714	1495	2019	1387	1703	1
3685	3747	5932	3303	6275	4274	5997	5174	5797	5086	5442	2
1142	1291	1857	1093	1838	2009	1774	1878	1924	1614	1769	3
1252	1391	1768	1065	2023	1591	1715	1815	2093	1577	1835	4
1402	1540	2223	1226	2875	1715	2110	2095	2162	1838	2000	5A
1456	1600	2221	1250	2760	1702	2004	2198	2285	1878	2081	5B
2163	2076	4237	2019	4890	2928	4363	4411	3716	3379	3548	6A
2474	2026	4542	2546	4259	3046	4408	4360	3746	3465	3606	6B
3459	3242	6802	3859	6200	4007	8123	6014	5434	5364	5399	7A
4127	2854	7232	4266	6109	3827	7889	6006	5565	5473	5519	7B
5137	4142	8679	5387	7509	5255	9716	7525	6701	6858	6779	8A
4683	3364	8604	5667	5848	4480	9149	6623	6836	6294	6565	8B
5839	6235	7957	5809	6524	5911	8286	8032	7565	6872	7219	9A
1983	4194	4305	1415	2074	3241	5137	3021	4701	3222	3962	9B
1641	2353	4470	1161	1887	2465	4353	2615	3526	2676	3101	10A
2118	2597	4834	1376	2410	2658	4684	2804	3785	3027	3406	10B
2276	2635	6152	2874	4541	3020	5936	4308	4095	4072	4084	11A
2060	2399	6229	2631	4355	2904	5756	3783	4170	3830	4000	11B
2971	2889	6385	3468	5510	3409	7159	4964	5057	4782	4919	12A
2867	2325	6790	3336	4678	3237	6858	4645	5023	4555	4789	12B
4006	2746	6596	3740	5929	4056	7023	5801	5253	5112	5183	13A
4104	2664	6581	4515	5678	3914	6913	5421	5587	5109	5348	13B
3481	2803	7099	4177	5645	4013	7184	5391	5199	5046	5123	14A
3201	2566	6788	3823	4820	3683	6704	5103	5129	4725	4927	14B
3922	4795	4265	1425	6559	3452	6087	5429	5480	4478	4979	15A
4244	4795	4706	1125	6058	3525	5808	5443	5589	4587	5088	15B
1499	1346	2213	1167	2618	1720	1991	2071	2902 [1]	1800	2322 [2]	16A
1577	1334	2149	1140	2148	1752	1859	2191	2874 [1]	1822	2320 [2]	16B
4314	1485	6442	778	5400	1752	6098	2186	2349 [4]	1865 [4]	2107 [4]	17A [3]
4085	1319	6569	914	5354	1636	6190	2167	2591 [4]	1917 [4]	2255 [4]	17B [3]
1507	1734	2469	4567	2243	4437	2418	6343	4789 [4]	4935 [4]	4862 [4]	18A [3]
1532	1906	2572	4736	2286	4469	2639	6236	4865 [4]	4981 [4]	4923 [4]	18B [3]
2713	2608	4871	1908	5311	3353	5407	4745	4620	4023	4322	19
1107	1688	2075	1041	3434 [5]	3180	3248	4945	..	..	3702 [6]	20–1
				1867 [5]	1927	2339	2209	2035 [7]	1794	1908 [8]	20–2
1616	1759	3029	1679	2618	1424	2597	2356	3132	2235	2684	21
2031	2922	3043	2559	4050	1274	2010	1703	3099	2481	2790	22

19 years, 1865–83. [5] See Note (*) to Appendix-Table I., p. 64. [4] The averages given for Plots 17A and 17B, or 18A and 18B); and those given for Plots 18A and 18 B of 10, 10 and 20 years ammonia-salts owing to a mistake at harvest. [6] Average of 4 years, 1880–83. See Note (*) to Appendix-Table I.,

APPENDIX-TABLE XXVII.—AVERAGE PRODUCE per ACRE, per ANNUM,

PLOTS.	DRESSED GRAIN.					
	Quantity.			Weight per Bushel.		
	16 Years, 1852–1867.	16 Years, 1868–1883.	32 Years, 1852–1883.	16 Years, 1852–1867.	16 Years, 1868–1883.	32 Years, 1852–1883.
	bush. pecks.	bush. pecks.	bush. pecks.	lbs.	lbs.	lbs.
0	17 2¼	14 3¼	16 0¾	58·1	58·6	58·4
1	15 0¾	10 3	12 3¾	57·8	58·3	58·1
2	35 0½	31 3¾	33 2	59·9	60·1	60·0
3	14 3½	11 1½	13 0½	57·4	58·3	57·8
4	16 0½	11 2¾	13 3½	58·0	58·2	58·1
5A	17 0½	13 0½	15 0½	58·7	58·7	58·7
5B	17 1¼	13 2	15 1¾	58·5	58·8	58·7
6A	26 2¾	20 3½	23 3	59·2	59·8	59·5
6B	27 1½	21 1¾	24 1¾	59·3	59·6	59·5
7A	35 3	29 1¼	32 2	59·2	59·8	59·5
7B	36 0¼	29 2¾	32 3½	59·2	59·7	59·5
8A	38 0½	34 2¼	36 1¼	58·7	59·8	59·3
8B	38 1½	33 2½	36 0	58·7	59·6	59·2
9A	35 2¾	36 3¼	36 1	58·1	59·3	58·7
9B	26 2½	20 1	23 1¾	56·5	56·5	56 5
10A	23 1¼	17 2¾	20 2	56·9	57·1	57·0
10B	27 1½	19 0½	23 1	57·9	57·3	57·6
11A	28 3½	23 3	26 1¼	57·1	58·4	57·8
11B	29 3½	22 0¼	25 3¾	57·3	57·9	57 6
12A	34 2¾	27 3¾	31 1¼	58·9	59·5	59·2
12B	34 2¼	26 3½	30 2¾	59·0	59·1	59·1
13A	33 2½	28 2½	31 0½	59·4	60·3	59·8
13B	34 1½	29 3¼	32 0½	59·4	60·1	59·8
14A	34 0½	29 2½	31 3½	59·0	59·7	59·4
14B	34 1¾	28 0¼	31 1	59·0	59·1	59·1
15A	32 2	28 3½	30 2¾	59·3	59·9	59·6
15B	33 3¼	29 2	31 2½	59·3	59·9	59·6
16A	39 1¾ (1)	14 2 (2)	24 2½	58·0 (1)	59·2 (2)	58·7
16B	39 2 (1)	14 2½ (2)	24 3	58·0 (1)	59·1 (2)	58·7
(3) 17A	17 3½	13 0½	15 1¾	58·7	58·6	58·7
(3) 17B	17 2¾	14 0¾	15 3¾	58·5	58·7	58·6
(3) 18A	31 3	27 3¼	29 3½	59·1	60·1	59·6
(3) 18B	31 3½	28 2	30 0¾	59·1	59·9	59·5
19	31 1	25 3¾	28 2½	58·4	58·6	58·5
20–1	..	..	23 1¾ (4)	..	..	59·7 (4)
20–2	14 2¾	12 0½	13 1¾ (5)	57·7	57·8	57·7 (5)
21	21 0¾	16 3¼	19 0	58·4	58·8	58·6
22	21 0	17 2¾	19 1¼	58·3	58·6	58·4

(1) Average of 13 years, 1852–'64. (Mixed minerals and ammonia-salts.)
(2) Average of 19 years, 1865–'83. (Unmanured.)
(3) On Plots 17A and 17B, and 18A and 18B, the manures have been alternated mineral manure on Plots 18A and 18B, in one year; mineral manure on Plots
(4) Average of 4 years, 1880–'83. See Note (4) to Appendix-Table I., p. 64.
(5) Averages of 16, 15, and 31 years only; as, in 1868, owing to a mistake

16 YEARS, 1852–67, 16 YEARS, 1868–83, and 32 YEARS, 1852–83.

Straw (and Chaff).			Total Produce (Grain and Straw).			Plots.
16 Years, 1852–1867.	16 Years, 1868–1883.	32 Years, 1852–1883.	16 Years, 1852–1867.	16 Years, 1868–1883.	32 Years, 1852–1883.	
lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	
1744	1256	1500	2847	2182	2515	0
1613	988	1301	2567	1656	2112	1
3788	3352	3570	6013	5365	5689	2
1535	1009	1272	2459	1721	2090	3
1606	1038	1322	2627	1770	2198	4
1704	1160	1432	2776	1976	2376	5A
1774	1217	1496	2865	2067	2466	5B
2811	2159	2485	4486	3477	3981	6A
2878	2200	2539	4598	3557	4077	6B
4087	3385	3736	6339	5251	5795	7A
4141	3471	3806	6418	5375	5894	7B
4750	4415	4583	7161	6626	6894	8A
4786	4179	4482	7213	6327	6770	8B
4626	4749	4688	6880	7084	6982	9A
3287	2318	2802	4975	3583	4279	9B
2579	1724	2151	4066	2839	3452	10A
2990	1888	2439	4724	3100	3912	10B
3085	2454	2769	4901	3965	4433	11A
3226	2369	2797	5101	3776	4438	11B
3792	2990	3391	5971	4773	5372	12A
3829	2890	3359	6011	4602	5306	12B
3817	3278	3548	5951	5110	5530	13A
3936	3345	3640	6123	5239	5681	13B
3818	3171	3495	5983	5051	5517	14A
3839	3026	3432	6012	4815	5413	14B
3651	3093	3372	5706	4930	5318	15A
3859	3143	3501	5996	5024	5510	15B
5218 (1)	1405 (2)	2954	7708 (1)	2322 (2)	4510	16A
5215 (1)	1399 (2)	2949	7718 (1)	2320 (2)	4513	16B
1854	1230	1542	2977	2055	2516	17A } (3)
1841	1326	1583	2953	2217	2585	17B } (3)
3596	3061	3328	5600	4824	5212	18A } (3)
3627	3098	3362	5635	4887	5260	18B } (3)
3411	2515	2963	5400	4155	4778	19
..	..	2206 (4)	..	..	3702 (4)	20–1
1612	1109	1369 (5)	2546	1863	2216 (5)	20–2
2212	1558	1885	3538	2612	3075	21
2182	1642	1912	3500	2740	3120	22

each year since 1852; that is, ammonia-salts on Plots 17A and 17B, and the mixed 17A and 17B, and ammonia-salts on Plots 18A and 18B, in the next year, and so on.

in carting, the produce could not be ascertained.

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

[*Reprinted from the Journal of the Chemical Society, June*, 1885. Vol. XLVII.]

ON SOME POINTS IN THE COMPOSITION OF SOILS; WITH RESULTS ILLUSTRATING THE SOURCES OF THE FERTILITY OF MANITOBA PRAIRIE SOILS.*

By Sir J. B. Lawes, Bart., LL.D., F.R.S., F.C.S., and J. H. Gilbert, Ph.D., LL.D., F.R.S., V.P.C.S.

This paper may be considered as a continuation of one read in the Chemical Section, at the meeting of the American Association for the Advancement of Science held at Montreal, in August, 1882, entitled—"Determinations of Nitrogen in the Soils of some of the Experimental Fields at Rothamsted, and the Bearing of the Results on the Question of the Sources of the Nitrogen of our Crops,"—and in order adequately to bring out the bearings of the new results, embodied in the present communication, it is desirable, first to summarise the main results and conclusions of the previous one.

The question of the sources of the nitrogen of our crops is one respecting which very conflicting views are still entertained; and it may at once be admitted that so long as the facts of agricultural production alone are studied, without knowledge of, or reference to, the changes in the stock of nitrogen in the soil, it would seem not unreasonable to assume that a large proportion of the nitrogen, at any rate of some crops, must be derived, in some way or other, from the atmosphere.

Yield of Nitrogen per Acre in Different Crops.

Obviously, it is a point of first importance to determine what really is the annual yield of nitrogen in different crops over a given area, excluding, as far as possible, the amounts due to unknown supplies by manure; thus, as far as practicable, limiting the source to the stores of the soil itself, and to the atmosphere. The Rothamsted field experiments, in which different crops have been grown for very many years in succession on the same land, both without nitrogenous manure, and with known quantities of such manure, afford valuable data of the kind required; and, in our former paper, the results were discussed in some detail. It must suffice here to summarise them very briefly.

The average yield of nitrogen per acre per annum was, in wheat, 32 years without manure 20·7 lbs., and 24 years with a complex

* Read before the Chemical Section, at the Montreal Meeting of the British Association for the Advancement of Science, September 2, 1884.

mineral manure 22·1 lbs.; in barley, 24 years without manure 18·3 lbs., and 24 years with a complex mineral manure 22·4 lbs.; in root-crops, 36 years (including 3 of barley), with a complex mineral manure 25·2 lbs.; in beans, 24 years without manure 31·3 lbs., and 24 years with a complex mineral manure 45·5 lbs.; in clover, 6 crops in 22 years, with 1 of wheat, 3 of barley, and 12 years of fallow, without manure 30·5 lbs., and with a complex mineral manure 39·8 lbs.; in clover on land which had not grown the crop for many years, 1 year 151·3 lbs.; in a rotation of crops, 7 courses, 28 years, without manure 36·8 lbs., and with superphosphate of lime 45·2 lbs.; in the mixed herbage of grass land, 20 years without manure 33 lbs., and with complex mineral manure, including potass, 55·6 lbs.; lastly, with Bokhara clover, 5 years, with mineral manure, 92 lbs. of nitrogen, per acre per annum.

Thus, the annual yield of nitrogen per acre, none being supplied in manure, was the least in the cereal crops, more in the root-crops, and much more still in the leguminous crops, whilst in a rotation of crops, in which roots and Leguminosæ were interpolated with cereals, the annual yield of nitrogen was very much greater than in cereals grown year after year on the same land.

But, an essential point to remark is, that in all the experiments on arable land, whether with cereal crops, root-crops, leguminous crops, or a rotation of crops, grown without nitrogenous manure, *the decline in the annual yield of nitrogen was very great;* and this was the case even when a full mineral manure was applied. Even with the deep-rooted *Melilotus leucantha* the crops of the sixth and seventh years show a considerable decline in yield.

The Sources of the Nitrogen of Crops.

The next question is—what are the possible sources, other than the soil itself, of the amounts of nitrogen annually yielded in crops over a given area, when none is supplied by manure? This part of the subject was considered in some detail in our former paper, as it has been on previous occasions. It is only necessary here to state very briefly the general results of these former inquiries.

1. *Combined Nitrogen in Rain, &c.*

In Liebig's earlier writings, he assumed the probability of a very much larger quantity of ammonia coming down in rain than he did subsequently, but even in his *Natural Laws of Husbandry*, published in 1863, he concluded that as much as 24 lbs. of nitrogen per acre may be annually available to vegetation from that source. It is obvious that such an amount would do much towards meeting the requirements of many of the crops the yield of nitrogen in which has been given above.

In 1852, Boussingault determined the amounts of ammonia in the rain collected in Alsace during a period of nearly six months. His average amount of ammonia per million of rain was somewhat less than that found at Rothamsted in 1853, 4, 5, and 6; with approximately the same annual rainfall in the two localities. The amount of combined nitrogen found in the Rothamsted rain at that time corresponded to a deposit of about 6 lbs. as ammonia, and about $\frac{3}{4}$ lb. as nitric acid, per acre per annum; or in all less than 7 lbs.; whilst more recent determinations made at Rothamsted lead to the conclusion that the total amount of combined nitrogen contributed in the rain and the minor measured aqueous deposits probably does not exceed 5 lbs. per acre per annum; including that as ammonia, as nitric acid, and in organic matter.

Determinations of ammonia and nitric acid in the rain of numerous localities on the continent of Europe have been made, and the mean result for nine places, some urban and some country, and representing in all the collection of 22 yearly periods, corresponds to an average annual supply of about $10\frac{1}{4}$ lbs. of combined nitrogen per acre per annum.

Upon the whole, therefore, we are disposed to conclude that the supply of combined nitrogen coming down in the measured aqueous deposits from the atmosphere, little, if at all, exceeds 5 lbs. per acre per annum, in the open country, in Western Europe.

With records of the amounts contributed in rain and the minor aqueous deposits, we come to an end of all quantitative evidence as to the amounts of combined nitrogen available to the vegetation of a given area from atmospheric sources; and it will be seen that the amount so available is very far from adequate to supply the quantities annually yielded in different crops grown without nitrogenous manure.

It is true that the minor aqueous deposits from the atmosphere are much richer in combined nitrogen than rain; and there can be no doubt that there would be more deposited within the pores of a given area of soil than on an equal area of the non-porous even surface of a rain-gauge. There is, however, no evidence enabling us to estimate how much may be available from this source, in addition to that determined in the collected aqueous deposits. The quantity will doubtless vary according to the character, and to the temporary mechanical condition, of the soil; and the quantity absorbed and retained may be influenced by the character of the vegetation with which the land is covered. Still, such as it is, the evidence at command bearing on the point, leads to the conclusion that the amounts so available are but small, and quite inadequate to make up the deficiency between the amounts supplied directly in rain, and those yielded in the crops grown without nitrogenous manure.

Other Supposed Sources of Combined Nitrogen.

Among other possible supplies of combined nitrogen to the soil from atmospheric sources, it has been supposed that, in the last stages of the decomposition of organic matter in the soil, hydrogen is evolved, and that this nascent hydrogen combines with the free nitrogen of the atmosphere, and so forms ammonia; or that in the oxidation of organic matter in the soil, there may be an evolution of ozone, which, combining with free nitrogen, forms nitric acid.

We have on former occasions given reasons for concluding that these supposed sources cannot be taken as accounting for the facts of growth. Indeed, such evidence as exists on the point, even supposing these actions take place at all, leads to the conclusion that any amounts of combined nitrogen so available must, like those due to direct condensation by the porous soil, be both limited and inadequate.

But if the supplies from the atmosphere to the soil are inadequate, may not there be direct supply from the atmosphere to the plant itself?

Here again, the conclusion arrived at, after careful consideration of the evidence available was, that even broad-leaved plants, such as the root-crops for example, which have been assumed to absorb a considerable quantity of ammonia from the atmosphere by their leaves, do not derive any material amount of their nitrogen in that way.

Lastly, comes the question whether plants assimilate the free nitrogen of the atmosphere, and whether some descriptions do so in a much greater degree than others.

On this point there is a great deal of experimental evidence at command; but the results are very conflicting, and we have concluded that the balance of the evidence is decidedly against the supposition that plants do assimilate the free nitrogen of the atmosphere.

To recapitulate: the amounts of combined nitrogen annually coming down in the measured aqueous deposits from the atmosphere in the open country are quite inadequate to supply more than a small proportion of the nitrogen assimilated by crops over a given area, when none is supplied by manure. With regard to other possible supplies of combined nitrogen to the soil, there is no direct quantitative evidence at command, but such evidence as does exist points to the conclusion that such supplies are at any rate very limited and inadequate. The same may be said of the supposed combination of the free nitrogen of the air within the soil; also of the supposition that plants take up any material proportion of their nitrogen from combined nitrogen in the atmosphere by their leaves. Finally, the balance

of direct experimental evidence is against the supposition that plants assimilate the free nitrogen of the atmosphere.

The Nitrogen of the Soil as a Source of the Nitrogen of Crops.

The special object of our former paper, as indicated by its title, was to record and discuss determinations of nitrogen in the soils of some of the experimental fields at Rothamsted, and to show the bearing of the results on the question of the sources of the nitrogen of the crops grown.

When it is borne in mind that a difference in the amount of nitrogen in the soil of 0·001 per cent, may represent a difference of 20 to 25 lbs. per acre in a layer 9 inches deep, it will be seen how difficult it is to obtain results which are applicable for estimating the loss or gain of the soil from one period to another. In our former paper, these difficulties were considered in some detail, and the methods of collecting and preparing samples of soils for analysis were described.

Further, it was concluded that, owing to the low actual percentage of nitrogen in subsoils, and to the proportionally great variation in the percentage in different samples taken from the same plot and to the same depth, obviously due to natural inequalities, and unconnected with the special history of the plot, it was in most cases misleading to attempt to estimate changes in the stock of the total nitrogen of the soil beyond a comparatively limited depth from the surface—in fact very little beyond the depth to which the soil is influenced by the mechanical operations in the case of arable land, and by active root-development in that of grass land. Accordingly, most of our calculations of *total nitrogen* in the soil have been limited to that in the first 9 inches of depth.

Although the results of the determination of *total nitrogen* in the subsoils of different plots are thus inapplicable for the calculation of the loss or gain of the soil to any considerable depth, yet the determinations of the amounts of nitrogen existing as nitric acid—that is, of nitrogen in a soluble, and, so to speak, migratory condition—in the subsoils of plots in different conditions, induced by cropping or manuring, have much significance. It is a special object of the present paper to bring forward the results of new determinations of nitrogen as nitric acid, in soils and subsoils of known history, in some cases to the depth of twelve times 9 inches, or in all to 108 inches.

In order that the bearing of these new results on the question of the sources of the nitrogen of our crops may be better understood, it is desirable first to summarise the results and conclusions of our

former paper, both as to the amount of total nitrogen, and the amounts of nitrogen as nitric acid, found in various soils.

The Experimental Wheat-field Soils.—In the case of the field in which wheat has now been grown year after year from 1844 up to the present time, samples of the soils of many of the plots were taken in 1865, after 22 crops had been removed, and again in 1881, when 16 more had been taken. In these samples, the nitrogen was determined by the soda-lime method, and in some of them the nitrogen as nitric acid also.

It has been stated that on the continuous wheat-plot without any manure, and on that with mineral, but without nitrogenous manure, there was a marked decline in the annual yield of nitrogen per acre in the crops. The determinations of nitrogen in the soils showed that, with this decline of yield in the crops, there was also a marked reduction in the stock of nitrogen in the soils.

Calculation further indicated that the soil had lost nitrogen in amount corresponding to about two-thirds the quantity removed in the crops and lost by drainage. The conclusion was, that the soil itself had contributed, at any rate the greater part of the nitrogen annually removed in the crop and lost by drainage. The combined nitrogen in the rain and minor aqueous deposits, together with that in the seed sown, would supply most of the remainder. Thus there was very little to be provided from all the other possible sources taken together.

The Experimental Barley-field Soils.—From some of the plots in the field which has grown barley every year from 1852 up to the present time, samples of soil were taken in 1868, and again in 1882. Between these dates 13 barley crops had been removed. On the plot which had received a complex mineral manure every year, but no nitrogen, the records of average annual yield of nitrogen in the crops showed a gradual decline over the later years; and the nitrogen determinations in the soils showed, as in the case of the wheat soils, a reduction in the stock of nitrogen in the first 9 inches of depth.

The Experimental Root-crop Soils.—With the exception of 3 years (1853, 4 and 5), when barley was taken without manure, roots have been grown on the same land from 1843 up to the present time. Samples of the soil were taken in 1870 only; but then from 35 different plots. Having only taken samples once, the condition of the land at different periods cannot be compared. But, in the case of 4 plots, one entirely unmanured, and 3 with purely mineral manure, every year, the percentage of nitrogen in the first 9 inches of depth was at that time, that is, after 27 years of experiment, found to be lower than in any other of the experimental fields; though deter-

minations made in samples from other parts of the same field, and also from an adjoining field, show much higher results.

Now, the yield of nitrogen in the root-crops was, in the earlier years, much higher than, and in the later as low as, in the case of the cereals; and it is quite consistent with the conditions of soil known to be favourable for the growth of root-crops, and with the amount of fibrous root they throw out near the surface, that their growth should lead to a greater reduction in the stores of nitrogen of the superficial layers than in the case of other crops. In fact, the conclusion is, that the dependence of root-crops for their nitrogen on the stores of the soil itself, or on supplies by manure, is as clearly established as in the case of the cereals.

The Nitrogen of the Leguminosæ.

It has been shown that the leguminous crops yield much more nitrogen per acre than either cereals or root-crops, but that when grown continuously without nitrogenous manure, they, like the other crops, decline in annual yield.

The Experimental Bean-field Soils.—These experiments were commenced in 1847, and continued with some breaks until 1878. Without manure, the yield of nitrogen was in the earlier years much higher than in the cereals; but it declined very much, and in the later years it was as low as in the cereals. With mixed mineral manure, including potash, the yield was throughout much higher, but still the decline was very great. In 1857, and in 1865, samples of the soils of some of the plots were taken, and in 1883 of a greater number. Confining attention to the unmanured and mineral manured plots, that is to the plots to which no nitrogenous manure has been supplied, the soils show a very distinct reduction in total nitrogen in the first 9 inches of soil.

The Experimental Clover-land Soils.—An attempt was made to grow clover many years in succession on the same land, the experiment commencing in 1849, and ending in 1877, that is, extending over a period of 29 years. In the early years, some good crops were obtained, and small cuttings at intervals afterwards; but the plant very frequently died off in the winter and spring succeeding the sowing of the seed, so that only 8 years have yielded clover. In 1 year wheat, and in 5 barley, was taken; and in 12 years the land remained fallow.

Notwithstanding that so few crops of clover were produced, that 6 grain crops were grown, and that the land was many years practically fallow, the effect of the interpolation of the clover was to increase the average annual removal of nitrogen from the land considerably beyond that obtained in cereals grown continuously.

In 1881, samples were taken from the clover plots in 5 places, where no nitrogen had been applied; and determinations of nitrogen in them showed nearly as low a percentage in the first 9 inches of depth, as in the soil of an adjoining plot which had been 30 years under alternate wheat and fallow without any manure, and as in the soil of the exhausted root-crop land.

It is significant that, after good crops of clover in the early years, when the land was in ordinary condition, but constant failure afterwards, the percentage of nitrogen in the surface soil should be nearly as low as with alternate wheat and fallow without manure.

In an immediately adjoining field, after 6 grain crops had been grown in succession by artificial manure, the land was divided, and, in 1873, on one half clover (sown in the spring of the previous year), and on the other half barley, was grown. In the clover crops 151·3 lbs., and in the barley only 37·3 lbs. of nitrogen were removed; yet, in the next year (1874), barley being grown on both portions, the one from which 151·3 lbs. of nitrogen had been removed in clover yielded 69·4 lbs. in barley, whilst the one from which only 37·3 lbs. had been removed in the barley yielded only 39·1 lbs. in barley again.

In October, 1873, after the clover and barley had been removed, samples of soil were taken from 10 places on each portion; and determinations showed that there was a considerably higher percentage of nitrogen in the first 9 inches of the clover land than to the same depth of the barley land. This result, and the increased crop of barley succeeding the clover, are quite consistent with what is known of the influence of a clover crop as a preparation for a succeeding cereal one. But the actual amount of gain of nitrogen indicated in the surface soil was greater than the amount removed in the clover crops, which it seems difficult to suppose would be the case; though comparative samples were again taken 4 years later, and these also showed a higher percentage in the clover soil.

It is obvious that the clover, and the surface soil of the clover ground, had gained nitrogen either from the atmosphere or the subsoil; nor do the facts of the experiment afford evidence of the source of the nitrogen. There is, however, nothing in favour of the view that the atmosphere is the source, excepting that an explanation is needed; whilst it will be seen further on that there is direct evidence that the nitrogen of the soil is at any rate the source of much of the nitrogen of the Leguminosæ.

In view of the signal failure of clover on the nitrogen-exhausted arable soil, it is of much interest that large, but still declining crops, have been grown on a small plot of rich kitchen-garden ground for 31 years in succession.

The experiment was commenced in 1854. Samples of soil were taken in October, 1857, and in May, 1879, that is, with an interval of 21 seasons of growth. In 1857, only one sample was taken, and only to the depth of 9 inches; but in 1879 three were taken, in each case to the depth of twice 9, or 18 inches.

In 1857, the first 9 inches of soil showed more than 0·5 per cent. of nitrogen, or nearly 5 times as much as the exhausted arable soil in which clover would not grow. It is true the garden soil would also be rich in all other constituents; but some portions of the arable soil where the clover failed had received much more of mineral constituents by manure than had been removed in the crops.

The determinations of nitrogen made in the three 1879 samples of soil agreed very well, and they showed a reduction of 29 per cent. of the total nitrogen of the first 9 inches of soil since 1857. The reduction corresponded to a loss of 2732 lbs. per acre in the first 9 inches of depth during the 21 years; and it is to be remarked that with this great reduction in the stock of nitrogen in the soil there has also been a great falling off in the clover-growing capability of the soil, though mineral manures have from time to time been applied to a portion of the plot.

As nearly as can be estimated, the yield of nitrogen in the clover crops corresponded to about 200 lbs. per acre per annum over the 21 years; whilst the estimated loss of nitrogen by the first 9 inches of soil is about 130 lbs. per acre per annum; corresponding approximately to two-thirds of the amount removed in the crops. There is, however, reason to suppose that in the case of soils to which excessive amounts of farmyard manure are applied, there may be a loss by the evolution of free nitrogen, and so far as this may have occurred in this garden soil, there will be the less of the loss to be credited to the growing clover. On the other hand, in 1879, that is, at the end of the period under consideration, the second 9 inches of depth showed about three times as high a percentage as the subsoils of the arable fields, and even nearly twice as high a percentage as the surface soil of the field where the clover had so frequently failed. It cannot be doubted, therefore, that the subsoil of the garden plot had contributed to the yield of nitrogen in the clover.

There is, in fact, in the results of this experiment on a rich garden soil, if not absolute proof, certainly very strong ground for concluding, that much, and perhaps the whole, of the nitrogen of the 30 years of luxuriant clover crops was derived from the stores of nitrogen of the soil itself—supplemented only by the small amount of combined nitrogen annually coming down in the measurable aqueous deposits, and that condensed within the pores of the soil.

The Experimental Mixed Herbage Soils.—Over a period of 20

years, the mixed herbage of permanent grass land yielded an average of 33 lbs. of nitrogen per acre per annum without manure, and 55·6 lbs. with a mixed mineral manure, containing potash, but no nitrogen. Whence comes the increased amount of 22·6 lbs., under the influence of the purely mineral manure? In 1870, that is after 20 crops had been removed, samples of the soils were taken, and the nitrogen determined in them. Calculated per acre, the results indicated that the first 9 inches of depth of the mineral-manured plot contained, at the end of the 20 years, 506 lbs. less nitrogen than the unmanured plot to the same depth; corresponding to an annual reduction of 25·3 lbs. of nitrogen, against 22·6 lbs. per acre per annum more yielded in the crop. The coincidence is very remarkable; and the result can certainly leave little doubt that the increased amount of nitrogen in the crops had its source mainly, if not exclusively, in the surface soil.

In the case of the large crops of clover growing on the ordinary arable soil, it was assumed that, so far as the nitrogen was derived from the soil, it was mainly from the subsoil; but in the case of the clover on the rich garden soil it was concluded that it came largely from the upper layers; and here again, in the case of the mixed herbage, it is supposed that the increased yield is derived from the surface soil. In the first place, the surface soil of the garden ground was about four times, and that of the grass-land about twice as rich as that of the arable land. Further, it is known that clover growing on ordinary arable soil throws out much deep root. Then, again, although in the case of the mixed herbage experiment there was a considerable increase in the amount of leguminous herbage under the influence of the mineral (potash) manure, it was chiefly of the *Lathyrus pratensis*, which throws out a very large amount of root near the surface. There was also, in the later years, a considerable increase in the amount of gramineous herbage, more than would be expected under the direct influence of mineral manures, judging from their effects on the cereals on ordinary arable land. But, in the mixed herbage experiment the increase of the grasses did not take place at all prominently until after an increased growth of Leguminosæ; the surface soil of the grass land was about twice as rich in nitrogen as ordinary arable soil; and the grasses developed were characteristically surface-rooting species.

The Melilotus leucantha, and Trifolium repens, Soils.—On the arable soil on which red clover had, for many years, entirely failed to grow, and the percentage of nitrogen in the surface soil had been reduced to a very low point, the deep-rooted Melilotus grew very luxuriantly for several years. The seventh crop in succession has now been taken. The heaviest crop was obtained in the fifth year, 1882; its contents of

nitrogen was between 140 and 150 lbs. per acre; and the average yield over the five years was about 92 lbs. In the sixth and seventh years the produce has been less; and less than on a second plot on which the same plant was grown for the first time in the sixth year. This result is indication that the growth is failing on the original plot. Still, the average yield of nitrogen per acre in this strong and deep-rooted plant, on soil where the much less powerful, yet still deep rooted red clover had entirely failed for many years, was over the 7 years between 70 and 80 lbs. per annum; whilst, side by side with it, both red and white clover, growing under exactly similar conditions of soil and season, yielded scarcely any produce at all.

After the removal of the very heavy crop of Melilotus in the fifth year, 1882, samples of soil were taken from the Melilotus and the white clover plots, to the depth of 6 times 9, or 54 inches.

For reasons already stated, the determinations of total nitrogen in subsoils are not applicable for calculations of the comparative condition of the two plots in that respect. But the following facts are of much significance. Determinations of moisture in the soils and subsoils, at each of the six depths, showed much less water remaining in the Melilotus than in the white clover soils; and the difference was by far the greater at the lower depths. Calculated per acre, it would appear that the Melilotus soil had lost to the depth of 54 inches, 540 tons more water than the white clover soil, and the action had doubtless extended lower still.

Thus the plant whose habit of growth, and especially whose range, and feeding capacity, of root, enabled it to take up much more water, and doubtless much more food, from the subsoil than the plant of weaker habit and more restricted root-development, assimilated a much larger amount of nitrogen over a given area, and a legitimate inference is that it had, in some way, derived more nitrogen, as well as water and other constituents, from the subsoil. Further evidence will be given on this point.

Nitrogen as Nitric Acid in Various Soils and Subsoils.

We now come to the consideration of evidence of another kind bearing upon the question of the soil-source of the nitrogen of our crops. It is in reference to this part of the subject that we have new and important results to communicate, but it will be desirable first to refer briefly to those which have already been published.

In the first place it should be stated that the water passing through three drain-gauges, containing respectively 20, 40, and 60 inches depth of unmanured and uncropped soil, and exposed to receive the rainfall, contained, taking the average of several consecutive years,

nitrogen as nitric acid corresponding to about 40 lbs. of nitrogen per acre per annum. Of this, perhaps not much more than 5 lbs., and pretty certainly less than 10 lbs., would be due to combined nitrogen in rain, and condensed by the soil from the atmosphere. There would thus be from 30 to 35 lbs. annually due to the nitrification of the nitrogenous matter of these unmanured soils.

The following Table (p. 392), shows the amounts of nitrogen as nitric acid, found to specified depths, in soils under known, and for the most part strictly comparable, conditions.

In the first experiment, the land had been under rotation for many years, with no other manure than superphosphate applied every fourth year; that is for the root-crop commencing each course of—roots, barley, beans or fallow, and wheat. The samples of soil were taken from parallel plots, the difference between the two being that one had grown beans, and the other had been fallow. It will be seen that, down to the depth of 18 inches, the bean-soil contained 25·8 lbs. less nitrogen as nitric acid than the fallow soil.

In the second experiment, the land received both mineral and nitrogenous manure at the commencement of each rotation, and here, three years after the manuring, there was more nitrogen as nitric acid found, to the depth of 18 inches, than on the superphosphate plot; but 28·3 lbs. less after the growth of beans than after fallow.

In the third experiment, the manuring was the same as in the second, the samples were taken at the same period of the rotation, four years later, and to the depth of 27 inches, instead of only 18. Here there were 40·3 lbs. less nitrogen as nitric acid, to 27 inches of depth, after clover than after fallow.

In these three experiments, there is pretty clear evidence that the leguminous crops, beans and clover, had taken up nitrogen as nitric acid from the soil.

The fourth experiment has reference to land which had been alternately in wheat and fallow, without any manure, for nearly 30 years. The samples of soil taken after the removal of the wheat show very little nitrogen as nitric acid in the first 9 inches of depth, and only traces in the second 9 inches; and to the depth of 18 inches there were 31·1 lbs. less than in the land that had been left fallow. It is seen how completely the wheat had exhausted the upper layers of the soil of their nitric acid.

The fifth and sixth divisions of the Table show the amounts of nitrogen as nitric acid found in the autumn, to the depth of 27 inches, in soils under ordinary conditions as to manuring and cultivation, after having been left fallow since the harvest of the previous year. The quantities still remaining within that depth correspond to not much less than 60 lbs. per acre.

TABLE I.

Nitrogen as Nitric Acid, in various Soils at Rothamsted.

Previous cropping and manuring.	Nitrogen as nitric acid, per acre, lbs.			
	First 9 inches.	Second 9 inches.	Third 9 inches.	Total.
Rotation (Superphosphate); Agdell Field, Sept. 1878.				
Fallow	22·3	14·0	—	36·3
Beans	7·2	3·3	—	10·5
Difference	15·1	10·7	—	25·8
Rotation (Full Manure); Agdell Field, Sept. 1878.				
Fallow	30·0	18·8	—	48·8
Beans	12·1	8·4	—	20·5
Difference	17·9	10·4	—	28·3
Rotation (Full Manure); Agdell Field, Sept. 1882.				
Fallow	40·1	14·3	5·5	59·9
Clover	11·4	4·8	3·4	19·6
Difference	28·7	9·5	2·1	40·3
Wheat and Fallow (Unmanured); Hoosfield, Sept. 1878.				
Fallow	28·5	5·2	—	33·7
Wheat	2·6	trace	—	2·6
Difference	25·9	5·2	—	31·1
Ordinary Cultivation; Claycroft Field, Oct. 1881.				
Fallow	16·4	26·5	15·9	58·8
Ordinary Cultivation; Foster's Field, Oct. 1881.				
Fallow	14·6	24·6	17·3	56·5

Lastly, in the experiment in which various leguminous plants were grown on the land on which red clover had so persistently failed, samples of soil were taken to the depth of 6 times 9 inches after the removal of the very heavy crop of *Melilotus leucantha*, and of the very meagre crop of white clover, in 1882. At each depth, the Melilotus soil contained less nitrogen as nitric acid than the white clover soil. It will be remembered that the Melilotus subsoil had lost very much more water than the white clover soil; and, excluding the first 9 inches of depth, the reduction in the nitrogen as nitric acid was greater at the lower depths. In all, to the six depths, the Melilotus soil contained 17·8 lbs. less nitric nitrogen than the white clover soil.

There is here pretty direct evidence that the nitrogen as nitric acid within the soil has been the source of at any rate some of the increased nitrogen of the Melilotus; though the quantity indicated is quite inadequate to account for the large amount of the increased yield. But the formation and the distribution of nitric acid within the soil are so dependent on the temporary conditions of temperature, moisture, and growth, that it is not to be expected that the amount found at any one time should account for the requirements of growth. Then, the action would doubtless extend deeper than is represented by the samples taken. It was suggested in the former paper that, with the strong and deeply distributing roots, the drawing up of water, and the greater disintegration and aëration accordingly, nitrification would probably be favoured in the lower layers, and that, if so, the supply would in a sense be cumulative. It was also suggested whether some of the nitrogen of the plant might not be taken up from the subsoil in other forms than that of nitric acid. These points will be further elucidated in the course of the discussion of the new results.

The New Results.

Nitrogen as Nitric Acid in Various Experimental Soils and Subsoils at Rothamsted.

We now come to the consideration of new determinations of nitrogen as nitric acid in various soils and subsoils. The determinations of nitric acid were made by Mr. D. A. Louis, by Schlösing's method, as nitric oxide, by the reaction with ferrous chloride.

Towards the end of July, 1883, after the removal of the crops, samples of soil were taken, not this time from the *Melilotus* plot, but from two *Vicia sativa* plots, and from one *Trifolium repens* plot, in each case to the depth of 12 times 9 inches, or in all to the depth of 108 inches. Both the *Vicia sativa* plots gave fairly luxuriant crops, but there was no plant at all on the white clover plot. Samples of soil were also taken at the same time, and to the same depths, from

the immediately adjoining unmanured alternate wheat and fallow land, from the portion which had been fallow since the harvest of the previous year.

The following table (p. 395) shows the amounts of nitrogen as nitric acid, calculated per acre, at each depth in the wheat-fallow land, in the *Trifolium repens* plot, and in each of the two *Vicia sativa* plots. It also shows the amounts, at each depth, more or less in the leguminous plot soils than in the wheat-fallow soil; and the amounts more or less in the *Vicia sativa* soils which yielded good crops, than in the *Trifolium repens* soil which gave no crop.

In the case of the wheat-fallow land, samples were taken at four places; and the figures given in the table are calculated from the results of determinations made in a mixture of the soils from the four holes, for each corresponding depth. In the case of each of the leguminous crop plots, samples were taken at two places; and, as in the case of the wheat-fallow plot, determinations of nitric acid were first made in a mixture of the samples from the two holes for each depth, but afterwards in the sample from each separate hole; and the results given for each depth are calculated from the mean of, first, the average of the determinations made in the samples from the individual holes, and, secondly, of the determinations made in the mixture from the two holes. Considerable differences were, in some cases, found in the amount of nitrogen as nitric acid in the separate samples from the same plot at corresponding depths; and these were found to be associated with great differences in the character of the subsoils, as to the proportions of clay, gravel, sand, &c., and with these, differences in the amounts of water, total nitrogen, &c. But whether the results for the individual holes, or for the two, be adopted, there is the same characteristic difference between plot and plot, as to their contents of nitrogen as nitric acid; that is to say, it is always very decidedly in the same direction, differing only more or less as to amount.

The first point of comparison that it is important to call attention to is the very marked difference between the amounts of nitrogen as nitric acid in the wheat-fallow land and in the *Trifolium repens* land.

At each depth, from the first to the twelfth, that is down to 108 inches in all, the *Trifolium repens* land contains much more nitrogen as nitric acid than the wheat-fallow land.

The two plots are absolutely adjoining in the same field. The one plot has been alternately wheat and fallow, without any manure, since 1850, or for more than 30 years. The other was sown with red clover 12 times during the 30 years 1848—1877; in 8 out of the last 10 trials, the plant died off in the winter or spring succeeding the

TABLE II.

Nitrogen as Nitric Acid, per acre, lbs., in the Soils and Subsoils of some Experimental Plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted. Samples Collected July 17–26, 1883.

Depths.	Wheat-fallow land, unmanured.	Series 1. Mineral manures.			+ or − wheat land.			+ or − Trifolium repens.	
		Trifolium repens. Plot 4.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.	Trifolium repens. Plot 4.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.	Vicia sativa. Plot 4.	Vicia sativa. Plot 6.
inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1—9	19·85	30·90	12·16	10·22	+11·05	−7·69	−9·63	−18·74	−20·68
10—18	8·05	27·73	4·11	2·72	+19·68	−3·94	−5·33	−23·62	−25·01
19—27	2·47*	8·44	1·37	1·08	+ 5·97	−1·10	−1·39	− 7·07	− 7·36
28—36	2·70	7·64	1·67	1·52	+ 4·94	−1·03	−1·18	− 5·97	− 6·12
37—45	1·62	9·07	4·58	2·51	+ 7·45	+2·96	+0·89	− 4·49	− 6·56
46—54	3·57	8·77	6·37	4·42	+ 5·20	+2·80	+0·85	− 2·40	− 4·35
55—63	3·84	7·92	7·16	4·52	+ 4·08	+3·32	+0·68	− 0·76	− 3·40
64—72	2·28	8·34	5·95	4·92	+ 6·06	+3·67	+2·64	− 2·39	− 3·42
73—81	1·48	8·27	4·54	4·81	+ 6·79	+3·06	+3·33	− 3·73	− 3·46
82—90	1·76	9·95	5·32	5·14	+ 8·19	+3·56	+3·38	− 4·63	− 4·81
91—99	2·94	9·16	5·66	6·40	+ 6·22	+2·72	+3·46	− 3·50	− 2·76
100—108	1·84	9·51	5·32	6·46	+ 7·67	+3·48	+4·62	− 4·19	− 3·05
Summary.									
1—27	30·37	67·07	17·64	14·02	+36·70	−12·73	−16·35	−49·43	−53·05
28—54	7·89	25·48	12·62	8·45	+17·59	+ 4·73	+ 0·56	−12·86	−17·01
55—81	7·60	24·53	17·65	14·25	+16·93	+10·05	+ 6·65	− 6·88	−10·28
82—108	6·54	28·62	16·30	18·00	+22·08	+ 9·76	+11·46	−12·32	−10·62
1—54	38·26	92·55	30·26	22·47	+54·29	− 8·00	−15·79	−62·29	−70·08
55—108	14·14	53·15	33·95	32·25	+39·01	+19·81	+18·11	−19·20	−20·90
1—18	27·90	58·63	16·27	12·94	+30·73	−11·63	−14·96	−42·36	−45·69
19—108	24·50	87·07	47·94	41·78	+62·57	+23·44	+17·28	−39·13	−45·29
1—108	52·40	145·70	64·21	54·72	+93·30	+11·81	+ 2·32	−81·49	−90·98

* According to the determinations on the mixture from the four holes, the result was 10·24 lbs., but this being obviously too high, determinations were made in the samples from each of the four holes separately, when the amount indicated in the third was found to be so abnormally high (= 25·9 lbs.) as to leave no doubt that there had been accidental contamination of the sample, and the results for the three other holes have accordingly been adopted.

sowing of the seed, in 4 of these without giving any crop, and in the other four only very small cuttings; and during the 30 years, consequent on the failure of the clover, 1 crop of wheat and 5 of barley have been taken, and the land was 12 years fallow. White clover (*Trifolium repens*) was then sown in 1878, 1880, 1881, and 1883. A small cutting was obtained in 1879, very small ones were taken in 1880 and 1881, and a small one in 1882, but none in 1883, so that the land was practically fallow when sampled. The plot had not received any nitrogenous manure for about 35 years. This and the other leguminous plant plots had, however, from time to time received mineral manures, containing phosphoric acid and potash, whilst the wheat land had not. It is known that potash manures favour the growth of *Leguminosæ*, and in the case of the soils of pasture land, the surface of which is much richer in nitrogen than that of ordinary arable soil, there is evidence that the increased amount of nitrogen taken up, both by the Gramineæ and the Leguminosæ, under the influence of the potash manure, is derived from the rich surface soil itself, and probably as nitric acid. Of course, if phosphoric acid and potash in available condition were deficient, their application would of itself enhance the rate of nitrification even in an arable soil poor in nitrogen; but the extremely limited effect of such manures when applied to such soils for the growth of cereals, points to the conclusion that little if any of the excess of nitrogen as nitric acid in the *Trifolium repens* land, compared with that in the wheat-fallow land, is to be attributed to the action of the phosphoric acid and potash independently of the growth of the *Leguminosæ*.

Lastly, in March, 1881, and again in July, 1883, the surface soil of both plots was found to be very low in nitrogen determinable by soda-lime; that of the clover-land containing not much more, and that of the wheat-fallow land rather less, than 0·1 per cent. According to the figures, the leguminous crop soils contained from 400 to 500 lbs. more combined nitrogen per acre in the first 9 inches of depth than the wheat-fallow soil. To the total depth of 108 inches, the plots show an average of not much less than 20,000 lbs. of combined nitrogen per acre; excepting that the *Vicia sativa* plot 6 shows considerably less than the others, owing to the sandy and gravelly character of the samples of its subsoil at the lower depths, whilst the *Trifolium repens* soil, the samples of which were more clayey, shows the highest of the series.

Thus, independently of the application of mineral manures to the leguminous plant plots, the characteristic difference in the history of the two plots now under consideration is—that the one had grown a gramineous crop alternately with fallow for more than 30 years, and

the other had, during the same period, grown six gramineous crops, and frequently been fallow, but it had been sown 12 times with red clover, and during the immediately preceding six years 4 times with white clover. That is to say, the chief distinction is, that the one had, from time to time, especially in the earlier and later years, grown a leguminous crop, whilst the other had not; and the leguminous crop soil is found to contain, down to the depth of 108 inches, nearly three times as much nitrogen as nitric acid as the gramineous crop soil.

The difference is much the greater in the first 18 inches of depth, indicating more active nitrification in the superficial layers; and this is doubtless mainly if not wholly due to the accumulation of more nitrogenous crop-residue from the leguminous than from the gramineous growth. It may here be mentioned that the amount of nitrogen removed in the *Trifolium repens* crops averaged over the preceding four years about 30 lbs. per acre per annum, but the immediately preceding crop (that of 1882) would probably remove between 60 and 70 lbs. How much beyond this would be contained in the crop-residue, and how much it would be in excess of that in the residue from the wheat crop, we have not the means of estimating; but it may safely be concluded that it would be considerably less than sufficient to supply the excess of about 90 lbs. of nitric nitrogen found to the depth examined in the soil of the *Trifolium repens* plot more than in the soil of the wheat-fallow plot; whilst, as has been shown, there was probably a material amount of drainage below that depth, which, according to the figures, would be much richer in nitric acid than any drainage from the wheat-fallow soil.

Part of the increased amount of nitric nitrogen in the lower layers of the leguminous plant soil may, however, also be due to washing down from the surface. On this point, it should be stated that, from September, 1882. to the end of February, 1883, the rain-gauge showed about 24 inches of rain, and the drain-gauges about 18 inches of drainage, so that the autumn and winter conditions had been conducive to both distribution and loss of nitric acid. In March and April there was very little of either rain or drainage; in May there was less than the average amount of rain, but more than the average amount of drainage; in June both rain and drainage were below average. Lastly, in July there was considerably more than average of both rain and drainage, nearly half of each occurring before the commencement of the soil-sampling on the 17th, and most of the remainder before its completion on the 26th.

Thus, not only had the conditions of the previous autumn and winter been favourable for distribution and loss, but the period immediately preceding and during the soil-sampling, which was also that of active

nitrification, were such as to favour distribution, if not even some loss by drainage.

It is, however, not easy to suppose that the whole of the excess of nitric nitrogen in the lower layers of the *Trifolium repens* soil is due to washing down from the surface.

That the increased amount of nitric acid found in the lower layers, not only of the *Trifolium repens*, but also of the *Vicia sativa* soils, is not wholly due to more active nitrification in the surface, and percolation downwards, would appear from the fact that the surface soil of each of the three leguminous plant plots, after more than 30 years of greater removal of nitrogen in produce, due chiefly to the frequent growth of leguminous crops, still remains somewhat richer in total nitrogen than that of the wheat-fallow plot. Or, if this is to be attributed to the accumulation of nitrogenous crop residue near the surface, in amount more than compensating for the exhaustion of nitrogen by the growth, this means, unless indeed we assume that it has come from atmosphere, that the nitrogen has been derived from the stores of the subsoil, and if as nitric acid, obviously not wholly from the surface soil.

An obvious difficulty in the way of the assumption that the increased assimilation of nitrogen by the *Leguminosæ* is due to a supply of nitric acid by the nitrification of the nitrogen of the subsoil, is that the direct application of nitrates as manure has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as nitrate of soda or nitrate of lime, unaccompanied by the other necessary mineral constituents in an available form; whereas, in the case of nitric acid being formed by direct action on the subsoil, it is probable that it will be associated with other constituents, liberated, and so rendered available, at the same time.

Upon the whole, the indication certainly is, that nitrification is more active under the influence of leguminous than of gramineous growth and crop-residue.

In Mr. Warington's paper "On Nitrification" (Trans., 1884, 637),* he states that samples of subsoil taken at a considerable depth, with precautions to exclude any roots or other organic matter, when introduced into a sterilised nitrogenous liquid, did not induce nitrification; the conclusion being that the subsoil was destitute of nitrifying organisms. This is obviously no proof that the nitrogenous matter of the subsoil would not nitrify if the organisms, with the other necessary conditions, were present. Indeed, results will be adduced further on, pointing to the conclusion that nitrification does take place in subsoils under such conditions.

* Also given in abstract at the Montreal Meeting of the British Association, September 2, 1884.

An obvious conclusion from the results given in the table is that, in the case of a soil under leguminous growth, the conditions are favourable for the development of the nitrifying organism; but, in what way, the evidence at present at command does not enable us to explain. If, however, this view should be confirmed, an important step would be gained towards the more complete explanation of the source of the nitrogen of the *Leguminosæ*.

In the case of the experiments now under consideration, the large amount of nitrogen as nitric acid was found in the soil where previously the deep-rooting red clover had frequently been sown and failed, but recently the shallow rooting *Trifolium repens* had been grown. The increased amount of nitrogen as nitric acid, not only in the upper but in the lower layers, must therefore have had its source, either wholly in the more active nitrification in the upper layers, and subsequent percolation downwards, against which view reasons have been given above, or it is only in part due to this source, and in a greater or less degree to the passage downwards of the nitrifying organism, and the nitrification of the nitrogen of the subsoil.

On the view here supposed, there would be much less difficulty in accounting for a large amount of the nitrogen of the subsoil thus becoming available to such deep and strong rooted plants as the *Melilotus leucantha*. With the penetration of the roots, channels are formed, by which, in addition to those made by worms, the nitrifying organism may pass downwards in association with recent and decomposable organic matter. There is direct evidence that much water is drawn up, and air, and some water, with its contents, must necessarily go down. We have thus all the conditions necessary for the supply of nitrogen as nitric acid to the roots, provided only the nitrogen of the subsoil is subject to nitrification.

On the assumption, therefore, that leguminous growth and crop-residue are favourable for the development of the nitrifying organism, it would follow that, if the conditions of soil are such as to allow of the establishment of a good plant, and to meet its requirements for mineral food, the greater its root development, the greater will be the amount of nitric acid formed, and of nitrogen so rendered available to the plant from the subsoil.

It is quite in accordance with such an explanation that it is only the deep and strong rooted *Leguminosæ* that yield very large amounts of nitrogen over a given area in their crops. It is further consistent with the supposition that the source of the nitrogen is the soil and not the atmosphere, that when such crops have been grown for some years, and have removed very large amounts of nitrogen, they cannot be grown again on the same land for many years afterwards; the explanation apparently being that, within the range of the roots of

the particular plant, the stock of nitrogen in a condition susceptible to nitrification, and perhaps also the supply of the necessary mineral constituents, in an available condition, had been for the time exhausted. It is also consistent with the idea of a soil-source, that when the same description of leguminous plant has been grown year after year until it fails, another description, with different root-habit and root-range, may grow luxuriantly for some years, and then in its turn decline or fail.

There is of course the alternative that the soil and subsoil may be the source of the nitrogen, and yet that the plant may take it up in other forms than as nitric acid, as ammonia, or as organic nitrogen.

We have shown that, in the growth of fungi, as in the case of "*Fairy rings*," both the organic nitrogen and the organic carbon of the soil are much reduced, and there is nothing in the conditions of growth of such plants, so far as they are known, at all inconsistent with the supposition that they take up their nitrogen and carbon directly from organic matter. The evolution of carbonic acid is a characteristic of the accumulative process of such plants; and it is found that the proportion of carbon to nitrogen finally fixed in the plant, is lower than the proportion of carbon to nitrogen lost by the soil.

The characteristic conditions of accumulation and growth of green leaved plants are, however, essentially different; and such as to require that clear experimental evidence should be adduced, before the conclusion can be accepted that they take up any material amount of their nitrogen and carbon from the same sources, and in the same manner, as the plants devoid of chlorophyll. Supposing the *Leguminosæ*, for example, were able to take up nitrogen directly as organic nitrogen from the subsoil; it must either be assumed that they take up carbon also, as do the fungi, or that they break up the organic compound, and in some way or other eliminate the carbon—which also must be eliminated in the case of nitrification.

Now, in the ordinary clay subsoil at Rothamsted, the relation of the carbon to the nitrogen is as 6 or 8 to 1, but in our common leguminous crops it is about 15 to 1. Hence, even if the whole of the carbon in association with nitrogen in the subsoil were taken up by the plant, it would not be sufficient to supply the whole of the carbon, and there would still be room for much assimilation from carbonic acid under chlorophyll action.

Or, it may be assumed that only the carbon of the *nitrogenous compounds* of the plant may be taken up with the nitrogen by the roots, from the subsoil. This would require less than $3\frac{1}{2}$ parts of carbon to 1 of nitrogen to be so supplied. So far, however, as direct experimental evidence is available on the point, it is, to say the least, doubtful, whether carbon supplied to the roots even as carbonic acid is

assimilated by green leaved plants; nor are we aware of any experimental evidence showing that such plants assimilate carbon presented to their roots in other forms of combination.

Thus, whilst, so far as existing knowledge goes, physiological considerations seem to militate against the supposition that green leaved plants take up carbon from organic matter in the subsoil, the only ground for assuming that they so take up their nitrogen is that as yet other explanations are quantitatively inadequate to account for the facts of growth.*

In defect of clearer evidence than we at present possess, leading to a conclusion which would approximate rather than differentiate the processes of accumulation of fungi and of green leaved plants, it will be of interest to follow up more closely, clues that seem to promise at least a more consistent solution of our difficulty as to the source of the nitrogen of the *Leguminosæ*.

This brings us to a consideration of the results given in the other columns of the Table II (p. 395).

It has been seen that the *Trifolium repens* soil showed more nitric nitrogen at every depth down to 12 times 9 inches, or in all to 108 inches, than the wheat-fallow soil. But the other columns show that in the case of both plots, where another leguminous plant, the *Vicia sativa*, had yielded fair crops, the amount of nitrogen as nitric acid was very much less. The inference is that the *Vicia* had taken up nitric acid and assimilated its nitrogen.

To go a little more into detail: each of the *Vicia* plots shows less nitric acid, at every depth down to 108 inches, than the *Trifolium repens* plot; but the difference is by far the greatest in the upper layers, and especially in the first 18 inches from the surface; and this is the range within which this plant throws out by far the larger amount of root. But the reduction is very distinct below this point; and the supposition is that water had been brought up from below, and with it nitric acid. In fact, the determinations showed less water in the soils of both the *Vicia* plots, at every depth, excepting the eleventh, than in the corresponding soils of the *Trifolium repens* plot, the eleventh depth of which showed the lowest proportion of soil of any in the whole series of plots and depths, and a very large amount of stones. Reckoning to the total depth of 108 inches, the mean for the two *Vicia* plots shows less water, corresponding to between 6 and 7 inches of rain, or to betweeen 600 and 700 tons of water per acre. Making full allowance for all irregularities at individual depths, or between hole and hole, due to variations in the character of the subsoils, there is here direct proof of much water, doubtless with its soluble contents, having been drawn up from the subsoil.

* The cases of the so-called "Insectivorous Plants" are obviously not parallel.

Calculated per acre, there is, in the one case 81·49 lbs., and in the other 90·98, lbs. less nitrogen as nitric acid in the *Vicia* soils than in the *Trifolium* soil, down to the total depth of 108 inches; nearly half of the deficiency being below the first 18 inches. Even supposing that no more nitrification had taken place in the *Vicia* soils where there was growth, than in the *Trifolium* soil where there was no growth, the difference which the actual results indicate would account for a large proportion of the nitrogen of the crops.

It has been shown, however, that the conditions of the weather had been such as to lead to the conclusion that there was probably some loss of nitric acid by drainage, which would obviously affect the *Trifolium repens* plot, where there was no growth, considerably more than the *Vicia* plots where there was growth, and a constant tendency to the drawing up of water with its contents. It is obvious that, so far as this has been the case, the amount of nitrogen as nitric acid found in the *Trifolium repens* plot down to the depth examined, does not represent the whole that had been formed within those limits. Now the amount of nitrogen as nitric acid remaining in the soil of one *Vicia* plot is estimated at 64·2 lbs. per acre, and the amount of nitrogen in the crop at 126 lbs., in all 190·2 lbs., or about 44·5 lbs. more than was found as nitric acid in the *Trifolium repens* soil; whilst in the case of the other *Vicia* plot, the amount of nitric nitrogen in the soil was estimated at 54·7 lbs., and the amount of nitrogen in the crop at 143·7 lbs., in all, in soil and crop, 198·4 lbs., or 52·7 lbs. more than was found in the *Trifolium repens* plot. On the supposition, therefore, that the whole of the nitrogen of the *Vicia* crops had been taken up as nitric acid, we have to assume that in the one *Vicia* plot 44·5 lbs., and in the other 52·7 lbs., more nitrogen as nitric acid was available than in the *Trifolium repens* plot to the depth examined; and this might be accounted for, partly by less loss by drainage from the *Vicia* plots, and partly by more nitrification under the influence of the growing crops, or their residues.

But, even if it be admitted that the source of the nitrogen of the *Vicia* crops is thus satisfactorily explained for the year in question, it is to be borne in mind that the same plots had grown the same plant in each of the five preceding years, with, on the two plots, an estimated average yield of nitrogen of rather over 40 lbs. in 1878, nearly 47 lbs. in 1879 and in 1880, nearly 70 lbs. in 1881, and between 140 and 150 lbs. in 1882; or an average of about 70 lbs. per acre per annum over the five immediately preceding years. But the amount of nitrogen taken up each year must have been much more than this, as each of the crops must have left nitrogenous crop-residue near the surface, which would yield nitric acid for the succeeding crop or crops. Much of the nitrogen of the removed crops and the residue combined,

must obviously be due to other sources than the original surface soil; and if to the subsoil, it must either have been taken up as organic nitrogen (or ammonia), or, as it would seem in 1883, as nitric acid; and in that case the annual nitrification beyond that of the previous crop-residue near the surface, must have yielded approximately as much nitrogen as was contained in the removed crops. As the *Vicia* crops were large in 1882, so also would their residue be proportionally large, and contribute a correspondingly large amount of nitric acid near the surface for the crop of 1883. But the crop of 1883 was nearly as large, and it, in its turn, would leave a correspondingly large residue, leaving approximately the whole of the nitrogen removed in the crop to be otherwise provided than from previous residue.

In conclusion, in reference to this series of experiments, it must be admitted that, without relying at all rigidly on the exact numerical results obtained under circumstances of so much difficulty as is involved in such an inquiry, these results, taken in conjunction with all that have been before adduced, justify the conclusion that much, if not the whole, of the nitrogen of the *Vicia sativa* crops had been obtained from nitric acid within the soil.

The next Table (III, p. 404), relates to the soil where beans had been grown almost continuously for about 30 years, the land had then been fallow for between 4 and 5 years, to 1882 inclusive, and the stock of nitrogen in the surface soil had been much reduced, and was in fact very low. Barley and clover were sown in 1883. The clover came up extremely well, and was very luxuriant even that year, much interfering with the growth of the barley; and this year, 1884, it has given two heavy crops.

It is certainly contrary to what would be anticipated, that, on this bean-exhausted soil, with its low percentage of nitrogen in the upper layers, very luxuriant crops of clover should be grown. Nor have we any data as to the changes in the soil and subsoil under the influence of this luxuriant growth. It is to be borne in mind, however, that the land had been fallow for several years, that clover had not been grown on it for perhaps 40 years or more, and that it succeeded a crop, though a leguminous one, of very widely different root-habit and root-range. Whether as the result of the fallowing or not, it is obvious that poor as the surface soil was in total nitrogen, it was in favourable condition, both as to nitrogen and mineral supply, for the establishment of a good plant. This accomplished, it may safely be concluded, that the plant would develop much root in the subsoil, that it would, directly or indirectly, draw up much water from below the surface, and that, with this, it would take up nitrogen as nitric acid, as well as other constituents, from the subsoil.

TABLE III.

Nitrogen as Nitric Acid per acre, lbs., in Soils of Experimental Plots; Beans many years in succession; Fallow last $4\frac{1}{2}$ years.

Geescroft Field, Rothamsted. Sampled April 9—13th, 1883.

Depths.	Without manure.	Mineral manure		Farmyard manure.
		Alone.	And ammonium salts or sodium nitrate.	
	Plots 1 and 2.	Plot 8.	Plots 9 and 10.	Plot 42.
inches.	lbs.	lbs.	lbs.	lbs.
1—9	4·28	3·34	3·46	13·57
10—18	5·52	6·69	5·81	8·76
19—27	4·81	4·33	4·12	7·70
28—36	2·69	2·33	4·14	8·51
37—45	2·68	1·25	2·28	4·36
46—54	1·90	1·05	2·34	1·85
55—63	2·60	0·81	1·48	1·71
64—72	3·47	0·92	1·75	4·00
		Summary.		
1—27	14·61	14·36	13·39	30·03
28—54	7·27	4·63	8·76	14·72
55—72	6·07	1·73	3·23	5·71
1—36	17·30	16·69	17·53	38·54
37—72	10·65	4·03	7·85	11·92
1—72	27·95	20·72	25·38	50·46

Not only was the total nitrogen in the surface soil very low (about 0·1 per cent. in the dry sifted soil), but the table affords direct experimental evidence that the amount of nitric acid already existing in the soil when the barley and clover were sown was extremely small. Even in the case of the farmyard manure plot, and much more so in that of the other plots, it was entirely inadequate to meet the requirements of the luxuriant crops of clover.

The soils were sampled from April 9—13, 1883. It has been already stated that the land had been fallow for several years, so that there would be a minimum amount of crop-residue near the surface; and since, during the autumn and winter of 1882—3, there had been a great excess of both rain and drainage, it could not be expected that there would be much of the probably limited amount

of nitric acid formed in the previous summer and autumn remaining in the soil in April. Indeed, excepting in the case of the farmyard manure plot, there is more nitrogen as nitric acid in the second and third, and in one case in the fourth depth, than in the first, thus affording direct evidence of washing down. In fact, in the first three depths, that is, down to 27 inches, there is only about half as much nitrogen as nitric acid as, to the same depth, in the wheat-fallow soil sampled in the following July, and there is also less in the next five depths.

Here, then, we have a surface soil with the total nitrogen very much reduced by previous treatment, and very low, in both surface and subsoil, very small amounts of ready-formed nitric acid, and probably a minimum amount of crop-residue near the surface for decomposition and nitrification, when the red clover was sown. Yet very luxuriant crops were grown, carrying off more than 200 lbs. of nitrogen per acre, and, of course, leaving a highly nitrogenous crop-residue besides.

Whence comes this nitrogen? The alternatives are, 1—that it has been supplied from the atmosphere, in favour of which view there is nothing excepting that it would afford an explanation otherwise not very obvious; 2—that it has been derived directly from the organic nitrogen of the soil and subsoil, for which again there is as yet no proof, whilst there are physiological reasons against it; 3—that under the influence of the once well started leguminous growth, with its excretions and residue, the development of the nitrifying organism is favoured, first in the upper and richer, and afterwards in the lower and poorer layers, and that thus the nitrogen of the soil and subsoil has been gradually rendered available for the exigencies of growth; and that the supply was largely derived from the subsoil may be inferred from the fact that, after the growth of clover, the surface soil is generally found to be richer in total nitrogen determinable by the soda-lime method. For this explanation, too, it is freely admitted that proof is wanting; but there is, at any rate, more evidence from analogy in its favour than for either of the other solutions suggested.

The next results relate to plots on which rotation experiments have been conducted through 9 courses of 4 years each, that is, over a period of 36 years in all. The course of cropping has been, 1—roots; 2—barley; 3—clover, or beans, or fallow; 4—wheat. The manures indicated at the head of the columns in the table (p. 406), were only applied for the roots commencing each course, that is, once in 4 years; and the samples of soil were taken after the wheat crop concluding the ninth course, and consequently four years after the last application of manure.

TABLE IV.

Nitrogen as Nitric Acid per acre, lbs., in Soils of Experimental Plots, after Rotation 36 years. Roots; Barley; Clover, or Beans, or Fallow; Wheat.

Agdell Field, Rothamsted. Sampled November 15, 1883, *to January* 4, 1884.

Depths.	Mineral and nitrogenous manure. Roots fed on the land.		Superphosphate only. Roots carted.	
	Fallow. Plots 1 and 2.	Clover or beans. Plots 3 and 4.	Fallow. Plots 13 and 14.	Clover or beans. Plots 15 and 16.
inches.	lbs.	lbs.	lbs.	lbs.
1—9	3·44	6·13	3·36	3·66
10—18	3·11	4·41	2·64	3·48
19—27	0·79	1·63	0·95	1·51
28—36	1·01	1·80	0·90	0·96
37—45	0·81	1·52	0·45	1·18
46—54	0·61	0·81	0·53	1·55
55—63	0·77	2·23	1·22	0·85
64—72	0·89	1·68	1·49	1·57
73—81	0.65	2·44	2·97	1·67
82—90	2·03	2·08	2·78	2·00
91—99	1·53	2·13	4·81	2·36
100—108	3·75	2·83	3·11	0·90
		Summary.		
1—27	7·34	12·17	6·95	8·65
28—54	2·43	3·63	1·88	3·69
55—81	2·31	6·35	5·68	4·09
82—108	7·31	7·04	10·70	5·26
1—54	9·77	15·80	8·83	12·34
55—108	9·62	13·39	16·38	9·35
1—18	6·55	10·54	6·00	7·14
19—108	12·84	18·65	19·21	14·55
1—108	19·39	29·19	25·21	21·69

The first two columns of the table show the amounts of nitrogen as nitric acid down to the depth of 12 times 9 inches, or in all to 108 inches, in the soils where a full manure, both mineral and nitrogenous, had been applied every fourth year; and the third and fourth columns show the amounts in those where superphosphate of lime only had been applied, once in four years; the determinations being made, in each case, four years after the last application.

Each of these plots is again divided into two:—One-half being

left fallow, and the other growing clover or beans, in the third year of the course. That is to say, from one-half—that in fallow—there is no crop, and therefore no nitrogen removed in the third year of the course, whilst from the other a highly nitrogenous leguminous crop, clover or beans, is removed.

A further distinction between the differently manured plots is, that on the highly manured plot the roots were fed on the land, whilst they were entirely removed from the superphosphate plot. Thus, the one plot is not only very much more highly manured, but it is otherwise subjected to much less exhausting treatment.

The soil sampling was conducted between November 15, 1883, and January 4, 1884, the operations being very much interfered with by rain. It has already been stated, that there was a great deal of rain, and a great deal of drainage, during the previous autumn and winter, 1882—3. There was, however, very little drainage in either March or April, a fair amount in May, very little in June, a good deal in July, scarcely any in August; but there were considerable quantities in September, October, November, and December.

Upon the whole, therefore, the conditions during the previous twelve months or more were such as to induce distribution, and loss, of nitric acid by drainage.

The first point to remark is that, under these circumstances, the amounts of nitrogen as nitric acid found are in all cases very small; the highest amount being little more than half as much as was found in the wheat-fallow soil in Hoosfield, sampled before the loss by drainage of August, September, October, and November. Next, there is a general tendency to an increase in the amount in the lower layers, indicating washing down, and probably loss below.

Comparing plot with plot, and taking first the highly manured and less exhausted plot, it is seen that the figures in the two columns are very consistent. The amount of nitrogen as nitric acid is higher at every depth (excepting the twelfth) where clover had been grown, than where the land had been fallow, in 1882. That is to say, where the land had been fallow there was no growing plant to take up the nitric acid formed; there would be a minimum of crop-residue, and the smaller amount of nitric acid would be subject to drainage, both throughout the fallow period, and during the succeeding very wet autumn and winter. On the other portion, the growing clover would take up nitric acid, and leave a highly nitrogenous crop-residue near the surface. There would thus be more nitric acid formed, and remaining, within the range of the soil-sampling; and as a matter of fact the wheat crop of 1883, succeeding the clover, was larger, and took up more nitrogen, than that after the fallow. Indeed, over the 36 years of the experiment, whilst the clover or bean plot has yielded an average of 68·4 lbs.

of nitrogen per acre per annum in the crops, the fallow plot has only yielded 47 lbs.; or deducting the amounts of nitrogen applied in manures, the yield in the crops of the clover or bean plot has been 34 lbs., and that of the fallow plot only 12·6 lbs. per acre per annum.

This experiment affords an illustration of the loss of nitrogen that the land may sustain by fallow in a wet season, and of the benefits arising from the ground being covered with a crop which takes up the nitric acid as it is produced; and obviously the effect will be the greater when that crop is a leguminous one if, as has been suggested, its growth and residue are favourable to the development of the nitrifying organisms, and the formation of nitric acid, the nitrogen of which is conserved by the plant.

We turn now to the results relating to the much more exhausted plot, receiving only superphosphate of lime every 4 years, and no nitrogen in manure, and from which the root-crops are entirely removed instead of being fed on the land. From the fallow portion of this plot, an average of 31·1 lbs., but from the clover or bean portion of 44·4 lbs. of nitrogen has been removed per acre per annum in the crops. In 1882, about 150 lbs. of nitrogen were removed in the crop on the clover portion, the fallow portion losing none except by drainage; and after this the wheat crop of 1883 removed rather more nitrogen from the fallow portion.

The influence of the clover crop residue is nevertheless still seen in the somewhat higher amount of nitrogen as nitric acid in the first six depths; whereas, with the tendency to passage downwards, rather than to drawing upwards, during the fallow period, there is more nitric acid in the lower layers of the fallow portion.

To conclude in relation to the results of these rotation plots:—they do not contribute very direct, or very important evidence, on the main point of our inquiry—that of the soil-source of the nitrogen of our crops generally, and of the *Leguminosæ* in particular; but so far as they go they are found, on detailed examination, to be consistent in their indications with those which have gone before, and which are more definite in character.

The Sources of the Fertility of some Manitoba Prairie Soils.

If then, the mineral constituents not being deficient, and being in available condition, the fertility of a soil is largely to be measured by the amount of nitrogen it contains, and the degree in which it is subject to nitrification, it becomes a matter of interest to determine the characters of virgin prairie soils in these respects.

In our former paper, given two years ago, we gave the determinations of nitrogen in some prairie soils.

In a sample of Illinois prairie soil, supplied some years ago by Sir James Caird to Dr. Voelcker for analysis, the amount of nitrogen found in it by him, and also at Rothamsted, corresponded to 0·25 per cent. in the dry mixed soil and subsoil; while in the separate surface soil Dr. Voelcker found 0·33 per cent.

Again, in 1882 between forty and fifty samples of soil from the North-west Territory, taken at intervals between Winnipeg and the Rocky Mountains, were sent over to the High Commissioner in London for exhibition. They were exhibited in glass tubes 4 feet in length, and were stated to represent the core of soil and subsoil to that depth. Samples of the surface soils of three of these were kindly supplied to us for the determination of nitrogen in them. The following results were obtained:—

	Per cent. nitrogen in dry soil.
No. 1. From Portage la Prairie, about 60 miles from Winnipeg, under cultivation several years	0·2471
No. 2. From the Saskatchewan district, 140 miles from Winnipeg, under cultivation less time than No. 1	0·3027
No. 3. About 40 miles from Fort Ellice, a virgin soil	0·2500

Now these soils are probably about twice as rich in nitrogen as the average of arable soils in Great Britain, and perhaps about as rich as the average of the surface soils of permanent pasture land; and as their nitrogen has its source in the accumulation from ages of natural vegetation, with little or no removal, except by drainage, and they do in fact yield large crops, it is to be supposed that they are not deficient in the necessary mineral supplies. Indeed, in Dr. Voelcker's report on four Illinois prairie soils, he calls attention to their richness in potash and other mineral constituents; the amount of lime, however, being somewhat low.

In the case of these soils, we did no more than determine the nitrogen by soda-lime. But it is obvious that if the views we have maintained in the preceding part of this paper are correct, it would be a matter of much interest to determine the degree of susceptibility to nitrification of such soils. In a short visit paid by one of us to Manitoba in the autumn of 1882, a few samples of soil were collected for examination, and it was also arranged at Winnipeg that special samples should be collected. But notwithstanding the infallible baggage-cheque system of the American continent, the bag containing the samples was lost, and the special samples from Winnipeg have not yet reached us, but are still promised.

However, the Deputy Minister of Agriculture at Winnipeg, Mr. Acton Burrows, sent a series of samples last year (1883), to be exhibited at the offices of the Canadian Pacific Railway Company in London; and by his directions, and with the kind co-operation of Mr. Begg, the Land Agent of the Company in London, we have been enabled to obtain fair and sufficient samples of those sent over as above referred to. As the Tables V, VI, VII, and VIII, which follow, recording the results, show, one series of samples come from Niverville, one from Brandon, one from Selkirk, and one from Winnipeg. In each case, four samples were taken, representing respectively the first, second, third, and fourth foot of depth.

In all the samples, we have in the first place determined the total nitrogen, and the total carbon.

Samples were then extracted with water, by the aid of the water-pump, and the nitrogen as nitric acid determined in the extracts. The amount of nitric acid so found in the sample as received being very largely dependent on the conditions of moisture and preservation of the sample, the results of the first determinations are of little significance. After the first extraction, each sample, in a suitable condition as to moisture, was exposed in a shallow dish, covered with a glass plate, and all were subject to the same conditions as to temperature, which, however, were not uniform in the different periods. Then, after a given time, at first 28 days, but afterwards generally for a longer and not always a uniform period, the sample was again extracted, and the nitrogen as nitric acid again determined; and as the Tables show, the process was repeated 8 times, the work extending from March, 1883, to April, 1884.

It is obvious that, by repeated extraction, the soluble mineral matters of the soils would be washed out; and it became a question whether the reduced nitrification in some cases might not be due to a deficiency of mineral matter for the development of the nitrifying organisms, or of the formation of nitrates. Hence, after the fourth extraction, potassium phosphate, magnesium sulphate, and calcium carbonate, were added to the samples. It was evident from the character of the extracts that too much of these had been added, and in the fifth extract scarcely any nitric acid was obtained. After this extraction, however, the action recommenced with some energy, and in the Tables the results obtained in the fifth and sixth extractions are given together.

Again, after the seventh extraction, it was decided to see whether the action would be increased if the exhausted soils were seeded with nitrifying organisms. Accordingly, 0·1 gram of rich garden soil was well mixed with each of the subsoils in which the action had much diminished, and the results obtained after this treatment are

given within brackets, thus [ ], in the last column of each of the Tables.

We now turn to the consideration of the results obtained. The percentages of nitrogen (determined by the soda-lime method) are given in the first column of Table V; and the percentages of carbon, and its proportion to the nitrogen, in the surface soils, are given in Table IX, p. 419. The amount of carbon found, and its proportion to the nitrogen, in some of the subsoils, are, however, so high, that it is obvious the samples were not quite free from particles of undecomposed vegetable residue, although all that was visible was picked out before the samples were submitted to analysis. The subsoil carbon results are therefore not recorded.

The first soil, that from Niverville, about 44 miles west of Winnipeg, had been broken up from prairie five or six years, and had grown 5 crops of cereals.

The percentage of nitrogen in the dry soil of the first 12 inches of depth is 0·261, or nearly twice as high as in the first 6 or 9 inches of ordinary arable land, and about as high as in the surface soil of pasture land, in Great Britain. Even the second 12 inches of depth is richer than our surface arable soils. The third 12 inches is about as rich as the second 9 inches of the Rothamsted soils, but the fourth is low. Here, however, we have a depth of 24 inches very much richer than the first 9 inches of our own arable soils.

The soil from Brandon, about 132 miles west of Winnipeg, was first broken up in 1882, back set in 1883, and grew 25 bushels of wheat per acre that year.

This soil is not so rich in nitrogen as that from Niverville. Still the dry soil of the first 12 inches of depth contains 0·187 per cent. of nitrogen, and is as rich as the first 6 or 9 inches of good old arable soil, and the second 12 inches is about equal to the exhausted surface soil at Rothamsted; the third 12 inches is about equal to the second 9 inches of the Rothamsted soils; but the fourth depth is very poor.

The soil from Selkirk was taken from a farm which had been in cultivation for 25 years, but from a portion near the buildings which had never been broken up.

Here it is seen that there is an extremely high percentage of nitrogen in the first 12 inches of depth (0·618), and in the second 12 inches as high a percentage as in ordinary pasture surface soil (0·264). The third and fourth depths are about as rich as the Rothamsted subsoils. It might be supposed that the first 12 inches had been contaminated by manure from the buildings, were it not that the second 12 inches also shows a high result.

Lastly, the soil from Winnipeg had been broken up from prairie about 5 years, had been ploughed and trenched, had been manured

TABLE V.

Percentage of Nitrogen in some Manitoba Prairie Soils and Subsoils, also Results showing the Amounts of Nitrogen Nitrified, on exposure for given Periods, &c.

Depths.	Per cent. nitrogen in dry soil.	Nitrogen as nitric acid per million dry soil.															
		Original.	Periods of exposure.														
			1st.		2nd.		3rd.		4th.		5th and 6th.*		7th.		8th.†		
Soil from Niverville.																	
inches.	per cent.		days.		days.		days.		days.		days.		days.		days.		
1—12	0·261	2·70	28	14·33	28	9·44	87	45·75	35	lost	79	(0·14)	28	4·65	49	9·32	
13—24	0·169	0·18	28	3·18	28	3·23	85	1·89	38	4·14	79	(3·14)	28	0·57	28	[6·66]	
25—36	0·069	0·62	26	0·38	28	0·35	82	0·34	38	0·11	79	(0·78)	28	0·24	28	[1·28]	
37—48	0·038	0·74	28	0·44	28	0·59	74	0·51	38	0·29	79	(1·10)	28	0·18	28	[0·63]	
Soil from Brandon.																	
1—12	0·187	0·23	28	9·18	28	8·82	87	33·55	35	12·51	79	(10·15)	28	6·94	49	8·34	
13—24	0·109	1·50	28	‡1·43	28	1·05	85	3·27	35	5·70	79	(4·03)	28	2·37	49	lost	
25—36	0·072	0·75	26	4·56	28	3·81	82	1·05	38	1·71	79	(0·79)	28	0·24	28	[2·75]	
37—48	0·019	1·40	28	‡0·52	28	0·28	74	0·18	38	0·09	79	(0·44)	28	0·16	28	[0·67]	
Soil from Selkirk.																	
1—12	0·618	3·94	28	48·13	28	34·77	87	58·83	35	24·90	79	(28·23)	28	21·73	49	17·39	
13—24	0·264	3·08	28	‡13·67	28	22·74	77	26·61	35	11·30	79	(14·98)	28	13·61	49	15·06	
25—36	0·076	0·52	28	0·99	28	1·86	71	1·08	35	0·45	79	(0·78)	28	0·27	28	[2·10]	
37—48	0·042	0·31	28	0·19	28	0·22	62	0·77	38	0·35	79	(0·83)	28	0·23	28	[0·69]	
Soil from Winnipeg.																	
1—12	0·428	132·37	28	38·09	28	28·85	88	57·75	35	35·03	79	(22·95)	28	21·23	49	28·26	
13—24	0·327	83·19	28	‡5·95	28	24·75	85	24·27	38	17·97	79	(21·79)	28	3·95	49	17·74	
25—36	0·158	36·02	28	12·40	28	17·64	77	7·94	40	12·02	79	(10·88)	28	2·14	28	[13·63]	
37—48	0·107	11·52	28	5·70	28	8·16	57	0·72	45	4·08	79	(0·25)	28	0·55	28	[10·41]	

* In the cases in which the results are given in parentheses, potassium phosphate, magnesium sulphate, and calcium carbonate were added to the soils after the 4th extraction.

† In the cases in which the figures are enclosed within brackets, thus [ ], the soils were seeded by 0·1 gram of rich garden soil after the 7th extraction; and the number of days given represents the period after seeding, before extraction. ‡ Results probably low

two or three times, and had grown very good crops of potatoes. It is unfortunate that the land had been manured, as an individual sample may, though there is no evidence that in this case it did, contain portions of undecomposed manure. Both the first and the second 12 inches of depth are very rich in nitrogen (0·428 and 0·327)—richer than the average of old pasture surface soils. The third depth is as rich as a good arable surface soil (0·158), and the fourth much richer than the Rothamsted second 9 inches (0·107).

To convey a more definite idea of the relative richness in nitrogen of these Manitoba prairie soils, it may be well to state that the nitrogen in the dry soil of the first 9 inches of depth of the arable soils at Rothamsted is sometimes as low as 0·1 and seldom exceeds 0·14 or 0·15 per cent.; that in the second 9 inches it ranges from 0·07 to little over 0·08 per cent.; in the third 9 inches from under 0·06 to about 0·07 per cent.; and that in the lower depths it is rather lower still. As a further indication of comparative fertility it may be added that old pasture land at Rothamsted contains in the first 9 inches from 0·25 to 0·30 per cent. of nitrogen.

Some soils, however, peaty soils for example, may contain a high percentage of nitrogen, but in such conditions as to be extremely slowly rendered available. What is the condition of the nitrogen of these rich prairie soils in this respect?

This is illustrated in the columns of the Tables showing the amounts of nitrogen as nitric acid found in these soils and subsoils, after exposure for successive periods under suitable conditions as to moisture and temperature. In Table V (p. 412), the quantities are calculated per million dry soil, for each period. In Table VI (p. 415), the amounts per million dry soil, per day, are given. In Table VII (p. 416), the percentage of the original nitrogen, which is nitrified within each period is given. Lastly, in Table VIII (p. 417), an approximate estimate is given of the amounts of nitrogen nitrified per acre, in each soil, from each depth, within each period, and during the total period of the experiments.

In the narrow columns of Table V, the number of days comprised in each period of exposure is recorded; some periods during which the samples were allowed to go and to remain dry, and the action thus arrested, not being included. It was at first intended that the periods should be uniformly 28 days; but owing to the pressure of other work it was impossible to adhere to this, and hence there are irregularities in the results, comparing period with period, in explanation of which the difference in the length of the periods must be taken into account; but they are also in part due to variations of temperature between period and period. On this point it may be stated that the temperature ranged over the several periods as follow:—

	Centigrade.
First period	15—24°
Second period	18—24
Third „	18—31
Fourth „	10—23
Fifth „	3·5—16
Sixth „	4—27
Seventh „	9—26
Eighth „	11—28

It will be seen that in the case of each set of soils the amount of nitrogen nitrified is very much the greater in the richer surface soil than in the poorer subsoils. It is also generally, though not uniformly, greater in the second than in the third, and in the third than in the fourth depth of 12 inches.

The results are, however, arranged in a more comparable form in Table VI, p. 415, which shows the average amount of nitrogen nitrified *per day*, per million of dry soil, over each period. It is there seen that in most cases, especially of the subsoils, the rate of nitrification was much less over the third and fourth than over the first and second periods.

As already said, after the fourth period, mineral consituents were added, but, from the results, obviously in excessive amount, so that over the fifth period there was scarcely any nitrification; and even taking the results of the fifth and sixth periods together, the rate does not appear to have been increased; whilst, over the seventh period compared with the fourth, it is in most cases, and in some of the subsoils, very much reduced. It will be observed that during parts of the fifth and sixth periods the temperature ranged low; but during the seventh period compared with the fourth, there was not much difference.

Lastly, the increase in the rate of nitrification over the eighth period compared with the seventh, in the case of the subsoils which had been seeded by the addition to them of only 0·1 gram of rich garden mould, is very great. These results are enclosed with brackets thus [ ].

The results as they stand are very striking; and assuming that their indications are not materially vitiated by the fact that some of the subsoils appear from their high amount of carbon to have contained particles of vegetable residue, they are of much interest and significance, affording evidence that the nitrogen of subsoils is subject to nitrification, provided only that the nitrifying organisms, and the other necessary conditions for nitrification, are not wanting.*

* Further experiments on the point are now in progress.

TABLE VI.

Manitoba Prairie Soils and Subsoils. Nitrogen Nitrified *per day*, per million dry soil, during successive periods of exposure.

Depths.	Periods of exposure.							Average.
	1st.	2nd.	3rd.	4th.	5th and 6th.	7th.	8th.	
				Soil from Niverville.				
inches.								
1—12	0·513	0·337	0·526	lost	0·002	0·166	0·190	(0·250)
13—24	0·112	0·115	0·022	0·109	0·040	0·017	[0·238]	0·072
25—36	0·015	0·013	0·004	0·003	0·010	0·009	[0·046]	0·011
37—48	0·016	0·021	0·007	0·008	0·014	0·006	[0·023]	0·012
				Soil from Brandon.				
1—12	0·326	0·315	0·386	0·357	0·128	0·248	0·170	0·268
13—24	0·051	0·038	0·038	0·163	0·051	0·085	lost	(0·054)
25—36	0·175	0·136	0·013	0·045	0·010	0·009	[0·098]	0·048
37—48	0·019	0·010	0·002	0·002	0·006	0·006	[0·024]	0·008
				Soil from Selkirk.				
1—12	1·721	1·242	0·676	0·711	0·357	0·776	0·355	0·701
13—24	0·488	0·812	0·346	0·323	0·188	0·486	0·307	0·364
25—36	0·035	0·066	0·015	0·013	0·010	0·010	[0·075]	0·025
37—48	0·007	0·008	0·012	0·009	0·011	0·008	[0·025]	0·011
				Soil from Winnipeg.				
1—12	1·360	1·030	0·656	1·001	0·290	0·758	0·577	0·693
13—24	0·213	0·884	0·286	0·473	0·276	0·141	0·362	0·348
25—36	0·443	0·630	0·103	0·301	0·138	0·076	[0·487]	0·249
37—48	0·204	0·291	0·013	0·090	0·003	0·020	[0·372]	0·102

The results would thus lend confirmation to the view that, especially in the case of deep-rooted plants, the subsoil may become an important source of nitrogen yielded up to them as nitric acid; for, in addition to the channels formed by worms, such plants will form others by their roots, and by their growth will cause the passage upwards of much water, and so induce the passage downwards, not only of air, but of other matters, nitrifying organisms included.

Table VII, p. 416, shows the *percentage of the original nitrogen*, of

the soils and subsoils, which was nitrified during each, and the total period of the experiments. The last column shows that, over the total period, from 4 to 5 per cent., or more, of the nitrogen of the richer soils and subsoils was so nitrified; but it is obvious that the conditions of these experiments cannot be compared with those of the soils in their natural conditions of exposure, moisture, and temperature.

TABLE VII.

Manitoba Prairie Soils and Subsoils. Percentage of original Nitrogen Nitrified, during successive periods of exposure.

Depths.	Periods of exposure.							Total.
	1st.	2nd.	3rd.	4th.	5th and 6th.	7th.	8th.	
Soil from Niverville.								
inches.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
1—12	0·55	0·36	1·75	lost	0·01	0·18	0·36	(3·21)
13—24	0·11	0·19	0·11	0·24	0·19	0·03	[0·39]	1·26
25—36	0·06	0·05	0·05	0·02	0·11	0·03	[0·19]	0·51
37—48	0·12	0·16	0·13	0·08	0·29	0·05	[0·17]	1·00
Soil from Brandon.								
1—12	0·49	0·47	1·79	0·67	0·54	0·37	0·45	4·78
13—24	0·13	0·10	0·30	0·52	0·37	0·22	lost	(1·64)
25—36	0·63	0·53	0·15	0·24	0·11	0·03	[0·38]	2·07
37—48	0·27	0·15	0·09	0·05	0·23	0·08	[0·35]	1·22
Soil from Selkirk.								
1—12	0·78	0·56	0·95	0·40	0·45	0·35	0·28	3·77
13—24	0·52	0·86	1·01	0·43	0·57	0·52	0·57	4·48
25—36	0·13	0·25	0·14	0·06	0·10	0·04	[0·28]	1·00
37—48	0·05	0·05	0·18	0·08	0·20	0·05	[0·16]	0·77
Soil from Winnipeg.								
1—12	0·89	0·67	1·35	0·82	0·53	0·50	0·66	5·42
13—24	0·18	0·76	0·74	0·55	0·66	0·12	0·54	3·55
25—36	0·78	1·12	0·50	0·76	0·69	0·14	[0·86]	4·85
37—48	0·53	0·76	0·07	0·38	0·02	0·05	[0·97]	2·78

For the same reason, the calculations *per acre*, given in Table VIII, must also be accepted with much reservation. Still, the results are

TABLE VIII.

Manitoba Prairie Soils and Subsoils. Estimated Amounts of Total Nitrogen, and of Nitrogen Nitrified, *per acre*, during successive periods of exposure.

Depths.	Total nitrogen per acre.	Nitrogen as nitric acid.							Total.
		Periods of exposure.							
		1st.	2nd.	3rd.	4th.	5th & 6th.	7th.	8th.	
		Soil from Niverville.							
inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1—12	7,308	40·1	26·4	128·1	lost	0·4	13·0	26·1	(234·1)
13—24	5,408	10·0	10·3	6·1	13·3	10·1	1·8	[21·3]	72·9
25—36	2,484	1·4	1·3	1·2	0·4	2·8	0·9	[4·6]	12·6
37—48	1,520	1·8	2·4	2·0	1·2	4·4	0·7	[2·5]	15·0
		Soil from Brandon.							
1—12	5,236	25·6	24·7	93·9	35·0	28·4	19·4	23·4	250·4
13—24	3,488	4·6	3·4	10·5	18·2	12·9	7·6	lost	(57·2)
25—36	2,592	16·4	13·7	3·8	6·2	2·8	0·9	[9·9]	53·7
37—48	870	2·4	1·3	0·8	0·4	2·0	0·7	[3·1]	10·7
		Soil from Selkirk.							
1—12	17,304	134·8	97·4	164·7	69·7	79·0	60·8	48·7	655·1
13—24	8,448	43·7	72·8	85·2	36·2	47·9	43·5	48·2	377·5
25—36	2,736	3·6	6·7	3·9	1·6	2·8	1·0	[7·6]	27·2
37—48	1,487	0·7	0·8	2·7	1·2	2·9	0·8	[2·4]	11·5
		Soil from Winnipeg.							
1—12	11,984	106·6	80·8	161·7	98·1	64·3	59·4	79·1	650·0
13—24	10,464	19·0	79·2	77·7	57·5	69·7	12·6	56·8	372·5
25—36	5,688	44·6	63·5	28·6	43·3	39·2	7·7	[49·1]	276·0
37—48	4,045	21·6	30·8	2·7	15·2	1·0	2·1	[39·4]	112·8

not without significance, as conveying an idea of how freely these soils will yield up their nitrogen in an available form, when subjected to favourable conditions of cultivation, and of drainage if need be, favouring aëration, with, at the same time, suitable moisture and temperature. It must be borne in mind, however, that this ready

susceptibility to oxidation of the nitrogen is a source of loss rather than of gain, if the nitrates are not taken up by crops, but are allowed to encourage the growth of weeds, or to be lost by drainage.

It should be added that qualitative examinations lead to the conclusion that these soils are not deficient in the necessary mineral constituents.* They are, in fact, virgin soils of great fertility, accumulated by ages of natural vegetation, with little or no removal. There is abundant evidence that they are capable of yielding large crops; but that, under present conditions, they do not, on the average, yield amounts of produce at all commensurate with their richness compared with the soils of Great Britain which have been under arable cultivation for centuries, there can be no doubt; for, according to official records, their average yield of wheat per acre is even considerably less than that of the United Kingdom.

That the rich prairie soils of the North-west do not yield higher amounts of produce than they do, is due in part to vicissitudes of climate, and to short seasons of growth, but largely to scarcity of labour, and consequent imperfect cultivation, leading, with other disadvantages, to a luxuriant growth of weeds. Then, again, in the early years of settlement, and until mixed agriculture and stock feeding can be had recourse to, and local demand arises, the burning of the straw, and the deficient production, or the disregard and waste, of manure, are more or less unavoidable, but nevertheless very exhausting practices. So long as land is cheap, and labour dear, some sacrifice of fertility is inevitable in the process of bringing these virgin soils under profitable cultivation; and the only remedy is to be found in increase of population. Still, the fact should not be lost sight of, that such practices of early settlement do involve a serious waste of fertility.

It will be of interest here to contrast the condition of soils of very different history, as to their percentages of nitrogen, and so far as we are able, of carbon also.

Table IX, p. 419, shows the characters, in these respects, of exhausted arable soils, of newly laid down pasture, and of old pasture soils, at Rothamsted, of some other old arable soils, of some Illinois and Manitoba prairie soils, and, lastly, of some very rich Russian soils.

From these results there can be no doubt, that a characteristic of a rich virgin soil, or of a permanent pasture surface soil, is a relatively high percentage of nitrogen and of carbon, and a high relation of carbon to nitrogen. On the other hand, a soil that has long been in arable culture is much poorer in these respects; whilst an arable soil under con-

* See reference to Dr. Voelcker's analyses of Illinois prairie-soil, p. 409; also an analysis of a Manitoba prairie-soil, by Dr. J. M. H. Munro, *Chem. News*, April 2, 1885.

TABLE IX.

Nitrogen and Carbon in Various Soils.

	Date of soil sampling.	In dry sifted soil.*			Authority.
		Nitrogen.	Carbon.	Carbon to 1 nitrogen.	
Rothamsted Arable and Grass Soils.					
Roots 1843–52; barley 1853–55; Roots 1856–69; mineral manures	April 1870	Per cent. 0·0934	Per cent. —	Per cent. —	Rothamsted.
Wheat 1843–44, and each year since; mineral manures	Oct. 1865	0·1119	1·039	9·3	,,
	Oct. 1881	0·1012	1·079	10·7	,,
Barley 1852, and each year since; mineral manures	Mar. 1868	0·1202	—	—	,,
	Mar. 1882	0·1124	1·154	10·3	,,
Arable laid down to grass (ten acres), spring 1879	Feb. 1882	0·1235	—	—	,,
(Barnfield), spring 1874	Feb. 1882	0·1509	—	—	,,
(Appletree field), spring 1863	Nov. 1881	0·1740	—	—	,,
(Dr. Gilbert's meadow), spring 1858	Jan. 1879	0·2057	2·412	11·7	,,
(Highfield), spring (?) 1838	Sept 1878	0·1943	2·403	12·4	,,
Very old grass land (The Park)	Feb. and Mar. 1876	0·2466	3·377	13·7	,,
Various Arable Soils in Great Britain.					
Mr. Prout's farm, Broadfield, surface	—	0·170	—	—	Voelcker.
,, Blackacre ,,	—	0·107	—	—	,,
,, Whitemoor ,,	—	0·171	—	—	,,
Wheat soil, Midlothian	—	0·22	—	—	Anderson.
,, Eastlothian	—	0·18	—	—	,,
,, Perthshire	—	0·21	—	—	,,
,, Berwickshire	—	0·14	—	—	,,
Red sandstone soil, England	—	0·18	—	—	Voelcker.
United States and Canadian Prairie Soils.					
Illinois, U.S. No. 1	—	0·30	—	—	Voelcker.
,, ,, No. 2	—	0·26	—	—	,,
,, ,, No. 3	—	0·33	—	—	,,
,, ,, No. 4	—	0·34	—	—	,,
Portage la Prairie, Manitoba, surface	—	0·247	—	—	Rothamsted.
Saskatchewan district, N.W. territory, surface	—	0·303	—	—	,,
40 miles from Fort Ellice, N.W. territory ,,	—	0·250	—	—	,,
Niverville, Manitoba, 1st 12 inches	—	0·261	3·42	13·1	,,
Brandon, ,, ,,	—	0·187	2·66	14·2	,,
Selkirk, ,, ,,	—	0·618	7·58	12·3	,,
Winnipeg, ,, ,,	—	0·428	5·21	12·2	,,
Russian Soils.					
No. 1, 12 inches	—	0·607	—	—	C. Schmidt.
No. 2, 8 ,,	—	0·467	—	—	,,
No. 3, 5 ,,	—	0·188	—	—	,,
No. 4, 6 ,,	—	0·130	—	—	,,
No. 5, 11 ,,	—	0·305	—	—	,,
No. 6, 17 ,,	—	0·281	—	—	,,
No. 7, 9 ,,	—	0·409	—	—	,,

* Calculated on soil dried at 100° C.

ditions of known agricultural exhaustion shows very low percentages of nitrogen and carbon, and a low relation of carbon to nitrogen.

In conclusion, it has been maintained by some that a soil is a laboratory and not a mine, but not only the facts adduced in this and in former papers, but the history of agriculture throughout the world, so far as it is known, clearly show that a fertile soil is one which has accumulated within it the residue of ages of previous vegetation, and that it becomes infertile as this residue is exhausted.

Summary and Conclusions.

1. The annual yield of nitrogen per acre in various crops, grown for many years in succession on the same land without nitrogenous manure, was found to be very much greater than the amount of combined nitrogen annually coming down in rain and the minor measurable aqueous deposits.

2. So far as the evidence at command enables us to judge, other supplies of combined nitrogen from the atmosphere, either to the soil or to the plant itself, are quite inadequate to make up the deficiency.

3. The experimental evidence as to whether plants assimilate the free nitrogen of the atmosphere is very conflicting; but the balance is decidedly against the supposition that they so derive any portion of their nitrogen.

4. When crops are grown year after year on the same land, for many years in succession without nitrogenous manure, both the amount of produce per acre, and the amount of nitrogen in it, decline in a very marked degree. This is the case even when a full mineral manure is applied; and it is the case not only with cereals and with root-crops, but also with *Leguminosæ*.

5. Determinations of nitrogen in the soils show that, coincidently with the decline in the annual yield of nitrogen per acre of these very various descriptions of plant, grown without nitrogenous manure, there is also a decline in the stock of nitrogen in the soil. Thus a soil-source, of at any rate some, of the nitrogen of the crops is indicated. Other evidence pointed in the same direction.

6. Determinations of the nitrogen as nitric acid, in soils of known history as to manuring and cropping, and to a considerable depth, showed that the amount of nitrogen in the soil in that form was much less after the growth of a crop than under corresponding conditions without a crop. This was the case not only with gramineous but with leguminous crops. It was hence concluded that nitrogen had been taken up as nitric acid by the growing crops.

7. In the case of gramineous crop-soils, the evidence pointed to the conclusion that most, if not the whole, of the nitrogen of the crops was taken up as nitric acid from the soil.

8. In the experiments with leguminous crop-soils, it was clear that some at any rate of the nitrogen had been taken up as nitric acid. In some cases, the evidence was in favour of the supposition that the whole of the nitrogen had been so taken up. In others this seemed doubtful.

9. Although in the growth of leguminous crops year after year on the same land without nitrogenous manure, the crop, the yield of nitrogen in it, and the total nitrogen in the surface soil, greatly decline, yet, on the substitution of another plant of the same family, with different root-habit and root-range, large crops, containing large amounts of nitrogen, may be grown. Further, in the case of the occasional growth of a leguminous crop, red clover for example, after a number of cereal and other crops, manured in the ordinary way, not only may there be a very large amount of nitrogen in the crop, presumably derived from the subsoil, but the surface soil becomes determinably richer in nitrogen, due to crop-residue.

10. It was found that, under otherwise parallel conditions, there was very much more nitrogen as nitric acid, in soils and subsoils down to a depth of 108 inches, where leguminous than where gramineous crops had grown. The results pointed to the conclusion that, under the influence of leguminous growth and crop-residue, the conditions were more favourable for the development of the nitrifying organisms, and, especially in the case of deep-rooting plants, of their distribution, thus favouring the nitrification of the nitrogen of the subsoil, which so becomes a source of the nitrogen of such crops.

11. An alternative was that the plants might take up at any rate part of their nitrogen from the soil and subsoil as organic nitrogen. Direct experimental evidence leads to the conclusion that fungi take up both organic nitrogen and organic carbon, but there is at present no direct experimental evidence in favour of the view that green-leaved plants take up either nitrogen or carbon in that form from the soil; whilst there are physiological considerations which seem to militate against such a view.

12. In the case of plots where *Trifolium repens* and *Vicia sativa* had been sown, each for several years in succession, on soil to which no nitrogenous manure had been applied for about 30 years, and the surface soil had become very poor in nitrogen, both the soil and subsoil contained much less nitrogen as nitric acid where good crops of *Vicia sativa* had grown, than where the more shallow-rooted *Trifolium repens* had failed to grow; and the deficiency of nitric nitrogen in the soils and subsoils of the *Vicia sativa* plots, compared with the amount in those of the *Trifolium repens* plot, was, to the depth examined, sufficient to account for a large proportion of the nitrogen of the *Vicia* crops.

13. It may be considered established, that much, if not the whole, of the nitrogen of crops is derived from nitrogen within the soil—accumulated or supplied; and that much, and in some cases the whole, of the nitrogen so derived, is taken up as nitrates.

14. An examination of a number of United States and Canadian prairie soils showed them to be very much richer in both nitrogen and carbon, to a considerable depth, than the surface soil of old arable lands in Great Britain, and about as rich, to a much greater depth, as the surface soil of permanent pasture land.

15. On exposure of portions of some of these rich prairie soils, under suitable conditions of temperature and moisture, for specified periods, it was found that their nitrogen was readily susceptible of nitrification, and so of becoming easily available to vegetation.

16. After several extractions, the subsoils almost ceased to give up nitric acid; but on seeding them with a tenth of a gram of rich garden soil containing nitrifying organisms, there was a marked increase in the rate of nitrification. This result afforded confirmation of the view that the nitrogen of subsoils is subject to nitrification, if under suitable conditions, and that the growth of deep-rooted plants may favour nitrification in the lower layers.

17. Under favourable conditions of season and of cultivation, the rich prairie soils yield large crops; but, under the existing conditions of early settlement, they do not, on the average, yield crops at all commensurate with their richness, when compared with the soils of Great Britain which have been under arable culture for centuries. But so long as the land is cheap, and labour dear, some sacrifice of fertility is unavoidable in the process of bringing these rich virgin soils under profitable cultivation.

18. A comparison of the percentages of nitrogen and carbon in various soils of known history, showed that a characteristic of a rich virgin soil, or of a permanent pasture surface soil, was a relatively high percentage of nitrogen and carbon. On the other hand, soils which have long been under arable culture are much poorer in these respects; whilst arable soils under conditions of known agricultural exhaustion, show a very low percentage of nitrogen and carbon, and a low proportion of carbon to nitrogen.

19. Not only the facts adduced in this and in former papers, but the history of agriculture throughout the world, so far as it is known, clearly show that, pre-eminently so far as the nitrogen is concerned, a fertile soil is one which has accumulated within it the residue of ages of natural vegetation, and that it becomes infertile as this residue is exhausted.

LONDON :
HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE.

ON

AGRICULTURAL INVESTIGATION;

BEING

A LECTURE DELIVERED OCTOBER 27, 1884,

AT

RUTGERS COLLEGE, NEW BRUNSWICK, N.J.

UNDER THE AUSPICES OF

THE NEW JERSEY AGRICULTURAL EXPERIMENT STATION,
THE STATE BOARD OF AGRICULTURE, AND
THE STATE AGRICULTURAL COLLEGE;

BY

JOSEPH HENRY GILBERT, M.A., LL.D., F.R.S.

OF ROTHAMSTED, ENGLAND.

AND SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD.

✠

PUBLISHED BY THE
SOCIETY FOR THE PROMOTION OF AGRICULTURAL SCIENCE.
1885.

LONDON:
REPRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.
1889.

NOTE ON DR. GILBERT'S LECTURE.

It has been announced that Sir John Bennet Lawes, in arranging for the perpetual maintenance of the great work of Rothamsted, makes provision for a representative of that establishment to visit America every other year and lecture at appropriate places.

Dr. Gilbert was in the United States in 1882, and when it was known that he was to come again in 1884, efforts were made to have him attend the fifth annual meeting of the Society for the Promotion of Agricultural Science. As his various engagements unfortunately prevented his being in Philadelphia at the time desired, arrangements were there made to secure lectures from him at other places. He accordingly visited Lansing, Michigan, and New Brunswick, New Jersey, for the purpose, and found appreciative audiences at both places.

The lecture at Rutgers College was under the joint auspices of the New Jersey Agricultural Experiment Station, State Agricultural College, and State Board of Agriculture.

The Society for the Promotion of Agricultural Science, having intended this lecture to be a part of its proceedings at Philadelphia, have asked and obtained permission to first publish the same in this pamphlet. For this purpose the text has been carefully revised and the tables verified by Dr. Gilbert. This kind attention is gratefully acknowledged by

THE EXECUTIVE COMMITTEE.

NOTE ON THE RE-PRINT IN 1889.

With the exception of a few typographical corrections, the addition of the *Table of Contents* at the top of the next page, and some corresponding cross-titles in the body of the pamphlet, this is strictly a reprint of the Lecture as published in America, as above referred to.

It may be added that, so far as the results relating to the Growth of Wheat are concerned (p. 7 *et seq.*), substantially the same matter formed the basis of a Lecture given at the Royal Agricultural College, Cirencester, on June 16, 1885, so that this may, so far, also stand for the separate publication of that Lecture, which was the first of a series given at Cirencester on the Rothamsted Experiments; the second being on Barley, the third on Root-crops, and the fourth on Potatoes, each of which has already been separately published.

J. H. GILBERT.

LECTURE ON AGRICULTURAL INVESTIGATION.

J. H. GILBERT.

CONTENTS.

	PAGES
INTRODUCTION, AND GENERAL STATEMENT	3–7
RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF WHEAT FOR 40 YEARS IN SUCCESSION ON THE SAME LAND . .	7–19
WITHOUT MANURE (p. 7).	
WITH FARMYARD MANURE (p. 8).	
WITH VARIOUS ARTIFICIAL MANURES (pp. 8–19).	
Effects of Nitrogenous Manures (pp. 9–14).	
Carbon per acre in Wheat and Barley (p. 10).	
Nitrogen accumulation, Chlorophyll formation, and Carbon assimilation (p. 11).	
Effects of the unrecovered Nitrogen of Manure on succeeding crops (p. 12).	
Effects of Mineral Manures (pp. 14–17).	
Special Results relating to Potash and Phosphoric Acid (p. 16).	
Influence of different Seasons (p. 17).	
Results on different Soils, and in different Localities (p. 18).	
PRODUCE, IMPORTS, AND CONSUMPTION OF WHEAT, IN THE UNITED KINGDOM	19
PRODUCE OF WHEAT AND INDIAN CORN PER ACRE, IN THE UNITED STATES	21
PRODUCE OF VARIOUS CROPS PER ACRE, IN MANITOBA	22
AMOUNTS OF NITROGEN AND CARBON IN VARIOUS SOILS . . .	23

Mr. President, Professors and Students of Rutgers College, and Ladies and Gentlemen:

I ESTEEM it a high honour and a great responsibility to be called upon to address you on the present occasion;—an honour because, perhaps, I am not assuming too much in supposing that I owe the invitation to do so to the fact that the joint labours of Sir John Bennet Lawes and myself, in the furtherance of agricultural progress, which have now extended over a period of more than forty-one years, are held in some appreciation in this country;—and a responsibility, because I know that I have before me representatives of the best agricultural science in the Eastern States.

On hearing from Sir John Lawes, before leaving home, that I might probably be asked to lecture at some Agricultural Institutions in America, I at once decided that it would be inappropriate for me to attempt to discuss, in any detail, American agricultural practices or experiments; that in these matters I should be a learner rather than a teacher; and that it would be more suitable for me to give some account of the results obtained at Rothamsted, leaving my audience to decide for themselves, in great measure, how far the facts and the conclusions were applicable to American conditions.

In Germany and France very much good work has been done, both in the laboratory and feeding-shed, during the last thirty years or more; but in Germany, at any rate, we have it on the authority of Prof. Mærcker of Halle, one of their leading agricultural chemists, that systematic field experiments are almost abandoned in that country. In 1880, Prof. Mærcker stated that belief in their value was greatly diminished, and that by some they were declared to be of no value. It

was objected that the chemists of the Agricultural Stations have neither the means nor the technical knowledge necessary for carrying out such experiments successfully; that neither the amount of land nor the funds at their disposal were such as to admit of any safe deductions for application in practical agriculture from the results; and that purely physiological problems could be better investigated in the laboratory or in the greenhouse. He remarked that, owing to the errors necessarily incident to field experiments conducted by those not acquainted with practical agriculture, the confidence of the practical farmer in the results has been shaken. Indeed, owing to the difficulties and the cost of such inquiries, if conducted in a truly scientific manner, so as to be applicable for the solution of questions of fundamental and general interest, Prof. Mærcker concluded that the only field experiments which it was practicable to carry out in Germany were such as should be conducted by the practical farmer himself, to test the applicability to practice, of results and conclusions otherwise arrived at; and that, to insure that even such experiments should not be misleading, similar ones should be conducted on different descriptions of soil, and for several years in succession.

That the great cost of scientifically conducted field experiments should have prevented the more extended prosecution of them, is perhaps not surprising when I tell you that the Rothamsted field experiments, independently of all the laboratory investigations connected with them, cost considerably more than £1000 annually; whilst those which have been undertaken by the Duke of Bedford at Woburn for the past seven years, on behalf of the Royal Agricultural Society of England, and which are under the direction of Dr. Voelcker, cost not much less than this.

At various institutions in America, and preëminently at the New Jersey Agricultural Experiment Station, very much good work is being done of the character prosecuted with so much success in Germany, and recommended by Prof. Mærcker to be still further followed up; and whilst such work should be continued and extended, surely investigations of a more permanent value, and of more general application, should not be neglected. Nor can it be supposed that in so wealthy a country as America, where there is so much munificence and public spirit displayed in all matters of progress, the *cost* of scientifically conducted agricultural experiments will be any obstacle.

This brings me to the special subject-matter of my lecture, which is to illustrate the value of *long continued* and *carefully conducted* experiments, by reference to the results of one series of such experiments conducted at Rothamsted,—namely, those on the growth of wheat for more than forty years in succession on the same land—*without manure, with farm-yard manure*, and with a *great variety of chemical manures*.

But, before entering upon the details of this subject, it will be well to give some account of the scope and plan of the whole investigation, of which these special results only form a part.

At Rothamsted, no questions of mere local interest or economy are undertaken. The object is rather to investigate the principles underlying fundamental practices; and whilst results obtained in one locality, on one description of soil, and with one character of climate, require to be carefully studied before conclusions applicable to other localities and to other countries can be drawn, yet it is believed that the results which have been obtained are of very general and wide application.

The general scope and plan of the field experiments has been—to grow some of the most important crops of rotation, each separately, year after year, for many years in succession on the same land, without manure, with farm-yard manure, and with a great variety of chemical manures, the same description of manure being, as a rule, applied year after year on the same plot. Experiments with different manures on the mixed herbage of permanent grass-land, on the effects of fallow, and on an actual course of rotation, without manure, and with different manures, have likewise been made. Field experiments have thus been conducted for the periods, and over the areas, indicated in the following table:

ROTHAMSTED FIELD EXPERIMENTS.

CROPS.	DURATION, YEARS.	AREA, ACRES.	PLOTS.
Wheat (various manures)	41	13	37
Wheat alternated with fallow	33	1	2
Wheat (varieties)	15	4–8	About 20
Barley (various manures)	33	4¼	29
Oats (various manures)	10[1]	¾	6
Beans (various manures)	32[2]	1¼	10
Beans (various manures)	27[3]	1	5
Beans alternated with wheat	28[4]	1	10
Clover (various manures)	30[5]	3	18
Various Leguminous Plants	7	3	17
Turnips (various manures)	28[6]	8	40
Sugar Beet (various manures)	5	8	41
Mangel Wurzel (various manures)	9	8	41
Total Root Crops	42		
Potatoes (various manures)	9	2	10
Rotation (various manures)	37	2½	12
Permanent Grass (various manures)	29	7	22

(1) Including 1 year fallow.
(2) „ 1 „ wheat and 5 years fallow.
(3) „ 4 years fallow.
(4) „ 2 „ „
(5) Clover, 12 times sown, 8 yielding crops, but 4 of them very small, 1 year wheat, 5 years barley, 12 years fallow.
(6) Including barley without manure 3 years (11th, 12th and 13th seasons).

Samples of all the experimental crops are brought to the laboratory. Weighed portions of each are partially dried and preserved for future reference or analysis. Duplicate weighed portions of each are dried at 100° C., the dry matter determined, and then burnt to ash. The quantities of ash are determined and recorded, the ashes themselves being preserved for reference or analysis. In a large proportion of the samples the total nitrogen is determined, and in some the amount existing as albuminoids, amides, and nitric acid. In selected cases, illustrating the influence of season, manures, exhaustion, &c., complete ash-analyses have been made, numbering in all more than 700. Also in selected cases, illustrating the influence of season and manuring, quantities of the experimentally grown wheat-grain have been sent to the mill, and the proportion and composition of the different mill-products have been determined. In the sugar-beet, mangel-wurzel, turnips, and potatoes, the sugar in the juice has, in many cases, been determined, by polariscope, or by copper, or both. In the case of the experiments on the mixed

herbage of permanent grass-land, besides the samples taken for the determination of the chemical composition (dry matter, ash, nitrogen, woody fibre, fatty matter, and composition of ash), carefully averaged samples have frequently been taken for the determination of the botanical composition.

Samples of the soils of most of the experimental plots have been taken from time to time, generally to the depth of nine, eighteen, and twenty-seven inches, and sometimes even to four times this depth. In this way more than fifteen hundred samples have been taken, submitted to partial mechanical separation, and portions of the sifted soil have been carefully prepared and preserved for analysis. In a large proportion of the samples the loss on drying at different temperatures, and on ignition, has been determined. In most, the nitrogen determinable by burning with soda-lime has been estimated. In many, the carbon, and in some the nitrogen as nitric acid, and the chlorine, have been determined.

Almost from the commencement of the experiments the rain-fall has been measured; for more than thirty years in a gauge of one-thousandth of an acre area, as well as in an ordinary small funnel-gauge of five inches diameter. From time to time the nitrogen as ammonia (and sometimes as nitric acid) has been determined in the rain-waters, also chlorine in many samples.

Three drain-gauges, for the determination of the quantity and composition of the water percolating, respectively through twenty inches, forty inches, and sixty inches depth of soil (with its subsoil in natural state of consolidation), have also been constructed. Each of the differently manured plots of the permanent experimental wheat-field having a separate pipe-drain, the drainage waters have been, and are frequently, collected and analysed.

For several years in succession, experiments were made to determine the amount of water given off by plants during their growth. In this way various plants, including representatives of the gramineous, the leguminous, and other families, have been experimented upon; also evergreen and deciduous trees.

Experiments upon the feeding of animals were commenced in 1847, and have been continued at intervals up to the present time. The following points have been investigated:

1. The amount of food, and of its several constituents, consumed in relation to a given live-weight of animal within a given time.

2. The amount of food, and of its several constituents, consumed to produce a given amount of increase in live-weight.

3. The proportion, and relative development, of the different organs or parts of different animals.

4. The proximate and ultimate composition of the animals, in different conditions as to age and fatness, and the probable composition of their increase in live-weight during the fattening process.

5. The composition of the solid and liquid excreta (the manure) in relation to that of the food consumed.

6. The loss or expenditure of constituents by respiration and the cutaneous exhalations—that is, in the mere sustenance of the living meat-and-manure-making machine.

Several hundred animals—oxen, sheep, and pigs—have been submitted to experiment. The amount, and the relative development, of

TABLE I.

Wheat grown for forty years in succession on the same land, Broadbalk Field, Rothamsted. Results showing the effects of exhaustion, and of manure-residue. Quantities per acre. Produce—Dressed Grain in bushels.

	14 Tons Farm Yard Manure, every year.	Without Manure every year.	Mixed Mineral Manure alone.	Mixed Mineral Manure alone, — *blue*; Ammonium Salts alone = 86 lbs. Nitrogen, — *yellow*; alternately.		Mixed Min. Manr. Am. Salts. 172 lbs. N. 13 years, 1852-'64. Unman'd since.	Mineral Manure alone—*blue*; Ammonium Salts alone (86 lbs. Nitrogen)—*yellow*; Min. & Amm. Salts, —*green*; Unmanured—white.	
Plot Nos.	2	3	5	17	18	16	10a	10b
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
1844	20½	15					15½	
1845	32	23¼					31⅝	
1846	27¼	18					27⅝	17⅝
1847	29⅞	16⅞					25¾	25¼
1848	25⅝	14¾					19¼	25⅝
1849	31	19¼					32⅝	32⅝
1850	28½	15⅞					27	18
1851	29⅝	15⅝					28⅝	28⅝
8 yrs. '44-'51	28	17⅝	29	30¼	28⅞	30¾	26	24⅜
1852	27⅝	13⅞	16⅞	24⅝	14⅝	28⅝	21⅞	22½
1853	19½	5⅞	10½	8⅜	19¼	25½	10	15½
1854	41½	21½	24½	44¼	23⅜	49⅝	34⅜	39¼
1855	34⅜	17	18¼	18	33¼	32⅝	20	28½
1856	36¼	14½	19½	31	17⅜	37⅝	24¼	27¾
1857	41¾	20	23¾	26¼	40½	49⅝	29½	34½
1858	38¾	18	18⅜	33½	21¾	41⅞	22⅝	27¾
1859	36¼	18⅝	20½	20½	32⅝	34⅝	19	25½
1860	32½	12⅞	15⅞	25¼	16¾	32⅜	15½	18⅝
1861	34⅞	11⅜	15½	18¾	32⅞	37	12⅜	16
1862	38⅜	16	17½	27⅜	18¾	36⅝	23½	24⅞
1863	44	17¼	19⅜	21¾	46¼	55⅜	39½	43⅜
1864	40	16½	16⅝	36½	17⅜	51⅜	32½	36¼
1865	37½	13⅜	14¼	17	31⅜	32⅜	25¼	30½
1866	32⅝	12½	13¾	26⅝	12⅜	17⅜	26¼	28½
1867	27½	8⅞	9¼	10¾	23⅝	14⅜	18½	19⅝
1868	41¾	16⅜	17⅜	37⅜	18⅜	22¾	24¾	27⅜
1869	38¼	14¼	15¾	16¾	22⅞	16½	20¼	19⅜
1870	36½	15	18⅝	34⅜	19	18¼	21¾	23¼
1871	39	9⅜	11⅜	16	28⅜	13½	10½	10
1872	31⅝	10¾	12¾	25½	13	13½	18	18¾
1873	26¾	11¾	12¾	11¾	20⅜	12¾	19⅜	20⅜
1874	39¼	11½	13	33¼	14	11⅞	25¼	27¼
1875	28⅞	8⅝	9¼	11⅜	25⅝	10½	12¾	14⅜
1876	23⅞	8½	10½	26½	10⅜	11	12½	14½
1877	24½	8⅞	11⅜	10	12⅝	9⅞	17¼	18¼
1878	28¼	12⅜	14¾	29	15¼	13⅝	27⅜	29⅜
1879	16	4¾	5⅝	3½	20⅜	4⅞	4	4⅝
1880	38⅜	11½	17¾	32¾	15	14⅜	10⅜	13½
1881	30¼	13¾	12¾	13¾	32	13½	18¼	19¾
1882	32¾	11	12½	31	15⅜	10¾	23⅜	26½
1883	35¼	13⅞	15⅜	15⅜	38¼	15⅞	17½	18⅜
AVERAGES.								
4 yrs. '52-'55	30⅝	14½	17⅜	16¼	30⅜	34	21½	26¼
4 yrs. '56-'59	38	17¾	20¾	21⅜	34⅜	41	23⅝	28⅞
4 yrs. '60-'63	37⅜	14⅜	17¼	18½	33	(1) 42⅜	22½	25¾
4 yrs. '64-'67	34⅛	12¾	13⅜	14½	29⅜	(2) 21⅜	25½	28⅜
4 yrs. '68-'71	38⅞	13¾	16	17⅜	30¾	17⅜	19¼	20
4 yrs. '72-'75	31½	10⅜	12	12⅜	26¼	12	18⅞	20¼
4 yrs. '76-'79	23	8½	10⅜	9¾	22⅝	9⅞	15¼	16⅜
4 yrs. '80-'83	34⅛	12½	14⅝	14⅜	33½	13¾	17½	19½
8 yrs. '52-'59	34⅜	16⅛	19	18⅛	32⅜	37½	22¾	27½
8 yrs. '60-'67	35¾	13½	15¼	16½	31¼	(3) 42⅜	24	27¼
8 yrs. '68-'75	35¼	12¼	14	15	28½	(4) 16⅜	19	20⅜
8 yrs. '76-'83	28⅝	10½	12⅝	12¼	27¾	11¼	16⅜	18⅜
16 yrs. '52-'67	35½	14⅞	17⅜	17¾	31¾	(5) 38⅝	23⅜	27⅜
16 yrs. '68-'83	31⅞	11⅝	13⅜	13⅝	28⅛	(6) 14⅜	17¾	19⅛
32 yrs. '52-'83	33½	13⅛	15¼	15⅜	30	24¾	20½	23¼
46 yrs. '44-'83	32⅜	14						

(1) Average of 5 years, 1860—1864, inclusive.
(2) Average of 3 years, 1865—1867, inclusive.
(3) Average of 5 years, 1860—1864, inclusive.
(4) Average of 11 years, 1865—1875, inclusive.
(5) Average of 13 years, 1852—1864, inclusive.
(6) Average of 19 years, 1865—1883, inclusive.

the different organs and parts were determined in two calves, two heifers, fourteen bullocks, one lamb, two hundred and forty-nine sheep, and fifty-nine pigs. The percentages of water, mineral matter, fat, and nitrogenous substances, were determined in certain separated parts, and in the entire bodies, of ten animals,—namely, one calf, two oxen, one lamb, four sheep, and two pigs. Complete analyses of the ashes, respectively, of the entire carcasses, of the mixed internal and other "offal" parts, and of the entire bodies, of each of these ten animals, have also been made.

From the data provided as just described as to the chemical composition of the different descriptions of animal, in different conditions as to age and fatness, the composition of the increase whilst fattening, and the relation of the constituents stored up in increase to those consumed in food, have been estimated. To ascertain the composition of the manure in relation to that of the food consumed, oxen, sheep, and pigs have been experimented upon. The loss or expenditure of constituents, by respiration and the cutaneous exhalations, has not been determined directly, but only by difference,—that is, by calculation, founded on the amounts of dry matter, ash, nitrogen, &c., in the food, and in the (increase) fæces, and urine.

Independently of the points here enumerated, the results obtained have supplied data for the consideration of the following questions:

1. The characteristic demands of the animal body, for nitrogenous or non-nitrogenous constituents of food, in the exercise of muscular power.

2. The sources in the food of the fat produced in the animal body.

3. The comparative characters of animal and vegetable food in human dietaries.

Results of Experiments at Rothamsted, on the Growth of Wheat for Forty Years in succession on the same Land.

Having given a brief outline of the scope and plan of the investigations that have been in progress at Rothamsted for so many years, I propose to draw my illustrations as to the character and significance of the results obtained, mainly from those relating to the growth of wheat for more than forty years in succession on the same land:

1. Without manure.

2. With farm-yard manure.

3. With a great variety of chemical manures, both individual constituents and mixtures.

Table I. gives the number of bushels of dressed grain per acre without manure, and with farm-yard manure, in each of the forty years, 1844 to 1883 inclusive; and on some of the artificially manured plots, mainly selected to illustrate the effects of exhaustion and of manure-residue. In most cases in this table, and in all cases in the subsequent tables, the results obtained on the artificially manured plots are only given for the last thirty-two of the forty years, as during the first eight years the manures were not the same year after year on the same plot as they were subsequently.

Without Manure.

After a five-course rotation since manuring (turnips, barley, peas, wheat, oats), the first experimental wheat crop was harvested in 1844. The highest yield of the series was 23¼ bushels in 1845, and the lowest

was 4¾ bushels in 1879. Other yields have been 21⅛ bushels in 1854, 20 in 1857, only 5⅞ in 1853, and only 8–9 bushels in 1867, 1875, 1876, and 1877.

In the lower division of the table (I.) the average produce is given for each four years, each eight years, each sixteen years, and for the thirty-two years from 1852 to 1883 inclusive; also for the whole period of forty years. Without manure, the average annual produce over the four-year period was 14½, 17¾, 14⅜, 12¾, 13¾, 10⅝, 8½, and 12½ bushels; over the eight-year periods, 16⅛, 13½, 12¼, and 10½; over the sixteen-year periods, 14⅞ and 11⅜; over the thirty-two years, 13⅛, and over the forty years, 14 bushels. With such wide variations due to season, it is very difficult to estimate the rate of decline due to exhaustion. Excluding the very bad seasons, the decline due to gradual exhaustion is reckoned at from one-fourth to one-third of a bushel per acre per annum.

It is estimated that over a period of thirty years, the unmanured plot yielded an average of 18.6 lbs. of nitrogen per acre per annum in the crop, and lost a minimum of 10.3 lbs. in drainage, in all 28.9 lbs.; whilst on the mixed mineral manure plot (5), it is estimated that the crop removed an average of 20.3 lbs. of nitrogen, and that at least 12 lbs. were lost by drainage, or in total 32.3 lbs. Further it is estimated that the soils lost to the depth of twenty-seven inches about two-thirds of these amounts; leaving, say, 10 lbs. more or less to be otherwise accounted for. Of this, the rain, &c., would supply 5 lbs., or perhaps rather more, and the seed about 2 lbs., so that there is but little to be provided from all other sources. Lastly, as at the commencement the soil was, agriculturally speaking, exhausted, the nitrogen supplied by it would be largely due to old accumulations.

Farm-yard Manure every Year.

In the application of farm-yard manure every constituent is supplied in excess. The highest yields of the series of years were 44 bushels in 1863, 41¾ in 1868, 41¼ in 1857, and 41⅛ in 1854. The lowest yields were 16 bushels in 1879, 19⅛ in 1853, 20½ in 1844, 23⅜ in 1876, and 24⅛ in 1877.

The average produce per acre per annum over each of the five eight-year periods was 28, 34⅜, 35¾, 35¼, and 28⅝ bushels. Excluding the first eight years, and several of the recent very bad seasons, the average produce is about 35 bushels per acre per annum.

On the farm-yard manure plot, the first nine inches of soil show a great accumulation; it is nearly twice as rich in nitrogen as any other plot, yet this richness is not proof against bad seasons; nor are the highest amounts of produce in the field obtained on this plot.

Thus, without manure, or with mineral manure alone, there is a gradual decline in yield, and with this a marked reduction in the nitrogen of the soil. With farm-yard manure, on the other hand, there is great accumulation, and yet not the fullest crops, a large proportion of the constituents becoming very slowly available.

Various Artificial Manures.

The next question is, which constituents of farm-yard manure are the most effective for wheat in this agriculturally exhausted rather heavy soil, with a raw clay subsoil. The first illustrations on this point will be drawn from Table II. (p. 9).

TABLE II.

Wheat grown for forty years in succession on the same land, Broadbalk Field, Rothamsted: commencing 1844.

Results showing the effects of different manures for 32 years, 1852–83 inclusive. *Quantities per acre. Produce*—DRESSED GRAIN IN BUSHELS.

	Superphosphate, and Sulphates Potash, Soda, and Magnesia.					Sodium Nitrate alone. =86 lbs. Nitrogen.
	Alone.	& Amm.-salts =43 lbs. Nitrogen.	& Amm. salts =86 lbs. Nitrogen.	& Amm.-salts =129 lbs. Nitrogen.	& Sodium Nitrate=86 lbs. Nitrogen.	
Plots.	5	6	7	8	9a	9b
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
1852	16⅞	20¾	26¾	27½	25½	24½
1853	10¼	18⅛	23⅜	23½	11½	10½
1854	24½	34½	45½	48⅝	38⅝	38⅞
1855	18½	28	33	31½	29⅛	25⅜
1856	19½	27⅝	36⅞	39⅛	32⅜	26
1857	23⅝	35⅛	44⅞	48⅜	43⅝	36½
1858	18⅞	28⅞	39⅛	41⅞	37⅛	23⅜
1859	20⅜	29⅞	34⅝	34½	30	24⅛
1860	15⅞	22	27⅝	31½	32⅛	19⅛
1861	15⅜	27⅛	35	35⅛	33⅜	13⅜
1862	17⅝	28½	35⅞	39½	43½	25⅞
1863	19⅛	39⅛	53⅛	55⅝	55⅛	41½
1864	16⅞	31⅛	45⅜	49⅞	51⅛	33½
1865	14½	25	40½	43⅛	44⅛	29⅛
1866	13½	20⅛	29⅞	32⅛	32½	30⅜
1867	9½	15⅝	22⅛	30½	29⅛	22⅛
1868	17⅛	28⅛	39⅞	46½	47⅛	27½
1869	15⅝	21⅛	28⅜	34⅝	39	24⅛
1870	18⅞	30½	40½	45½	45⅛	26½
1871	11⅞	17	22½	27½	34½	17⅜
1872	12⅝	20½	29⅝	35⅛	40⅝	23⅜
1873	12⅜	15⅞	22	27½	35⅞	21⅞
1874	13	25⅞	39½	40½	38½	21⅛
1875	9½	16⅜	25⅞	30	30½	16½
1876	10½	15⅝	23½	29⅛	33⅜	13
1877	11⅛	14⅛	19⅞	24⅝	40⅛	27⅝
1878	14⅜	22⅝	31½	38⅛	37½	23⅜
1879	5⅛	10½	16½	20⅝	22	4⅝
1880	17⅝	27	34½	35⅜	34⅛	10½
1881	12⅜	21⅝	26⅜	30⅝	35½	22⅝
1882	12½	23⅛	35⅝	37	31⅞	24⅜
1883	15⅝	27⅛	36⅛	41⅞	43⅛	19⅛
AVERAGES.						
4 yrs. '52–55	17⅜	25½	32½	32⅝	26½	24⅝
4 yrs. '56–59	20⅝	30½	38⅞	41	36	27⅛
4 yrs. '60–63	17½	29⅜	38	40⅜	41⅜	25½
4 yrs. '64–67	13⅜	23⅛	34½	39	39½	29
4 yrs. '68–71	16	24⅜	32⅜	38½	41⅜	23⅞
4 yrs. '72–75	12	19⅜	29½	33⅜	36⅜	20⅞
4 yrs. '76–79	10⅛	15⅞	22⅜	28½	33½	17½
4 yrs. '80–83	14⅜	24⅞	33½	36½	36½	19½
8 yrs. '52–59	19	27⅞	35½	36⅞	31⅛	26½
8 yrs '60–67	15½	26½	36½	39⅜	40½	27⅛
8 yrs. '68–75	14	22	31	36	39	22⅜
8 yrs. '76–83	12⅝	20⅜	28	32½	34⅜	18½
16 yrs. '52–67	17⅛	27	35⅞	38½	35⅜	26⅜
16 yrs. '68–83	13⅜	21½	29⅜	34⅛	36⅞	20½
32 yrs. '52–83	15½	24⅛	32⅜	36½	36½	23½
Excess of average crop over Plot 5 in bush.	——	8⅞	17½	21	21	8½

Taking the average for each eight or sixteen years of the thirty-two, it is seen that in every case, even with full mineral as well as nitrogenous manure, there is more or less decline in the later periods, including so many bad seasons; excepting on 9a, where the nitrate of soda is always applied in the spring. The low results or great decline, on 9b, where the nitrate is used alone, show the want of minerals.

The average of the thirty-two years of mineral manure alone shows an increase of only 2½ bushels over that of the unmanured plot, though during the preceding eight years it had been manured, whilst the unmanured plot had already grown eight unmanured wheat crops. The addition to the mineral manure of the first 43 lbs. of nitrogen (plot 6) gives an average annual increase of 8⅞ bushels, the second 43 lbs. (plot 7) an increase of 8⅝, and the third 43 lbs. (plot 8) only 3½ bushels increase. This result affords an illustration of the inapplicability of conclusions from manure experiments, when the condition of the land is too high already, or when an excess of manure is applied. A given quantity of nitrogen in the form of nitrate, yielded more produce than an equal quantity in the form of ammonia. The nitrate, being always applied in the spring, was not subject to winter drainage. It is, however, very soluble, and becomes rapidly distributed and available; but it is, at the same time, very subject to drainage after sowing, if heavy rains follow. Prior to 1878, the ammonium-salts were applied in the autumn, and a great loss of nitrogen by winter drainage, chiefly as nitrates, was proved. To the loss of nitrogen by drainage reference will be made further on.

Thus, minerals not being deficient, the increase was in proportion to the available nitrogen, when it was not applied in excess.

It will be of interest here to call attention to the actual amounts of carbon assimilated per acre per annum in wheat, and in barley, under different conditions of manuring; also to the increased amount assimilated under the influence of nitrogenous manures.

In Table III. are shown the estimated amounts of carbon, yielded per acre per annum, in wheat over twenty years, and in barley over twenty years; each with the complex mineral manure alone, and each with the same mineral manure and given quantities of nitrogen in addition, supplied as ammonium-salts, or as nitrate. The gain of carbon by the use of the nitrogenous manure is also given.

TABLE III.

Yield and gain of Carbon per acre per annum in crops at Rothamsted.

	Average Carbon per acre, per annum.	
	Actual	Gain.
Wheat 20 years, 1852–1871.		
	lbs.	lbs.
Complex Mineral Manure	988	——
Complex Min. Man. and 43 lbs. Nitrogen, as Ammonia	1590	602
Complex Min. Man. and 86 lbs. Nitrogen, as Ammonia	2222	1234
Complex Min. Man. and 86 lbs. Nitrogen, as Nitrate	2500	1512
Barley 20 years, 1852–1871.		
Complex Mineral Manure	1138	——
Complex Min. Man. and 43 lbs. Nitrogen, as Ammonia	2088	950

It is quite evident that in the case of these gramineous crops, wheat and barley, which contain a comparatively low percentage of nitrogen, and assimilate a comparatively small amount of it over a given area, there was a greatly increased amount of carbon assimilated by the addition of nitrogenous manure alone. In the case of the wheat, there was much more effect from a given amount of nitrogen supplied as nitrate, which was always applied in the spring, than from an equal quantity as ammonium-salts, which were applied in the autumn, and the nitrogen of which was subject to winter drainage. There is also more effect from ammonium-salts applied to barley than to wheat; the application having been made for the former in the spring, and for the latter in the autumn. It should be observed that there was this greatly increased assimilation of carbon in the wheat and in the barley for more than twenty years, without the addition of any carbon to the soil. It is, indeed, certain that, in the existing condition of our old arable soils, the increased growth of our staple starch-yielding grains is greatly dependent on a supply of nitrogen within the soil. It is equally certain that the increased production of sugar in the gramineous sugar-cane, in the tropics, is likewise greatly dependent on the supply of nitrogen within the soil.

It will further be of interest to call attention to the connection between nitrogen accumulation, chlorophyll formation, and carbon assimilation.

TABLE IV.

Relation of Carbon assimilation to Nitrogen accumulation, and to Chlorophyll formed.

	Nitrogen, percentage in Dry Matter.*	Relative Amounts of Chlorophyll.	Carbon per acre per annum=lbs.	
			Actual	Difference.
HAY.				
Gramineæ	1.190	0.77	—	—
Leguminosæ	2.478	2.40	—	—
WHEAT.				
Plot 10a	(1.227)	2.00	1398	-824
Plot 7	(0.566)	1.00	2222	—
BARLEY.				
Plot 1a	(1.474)	3.20	1403	-685
Plot 4a	(0.792)	1.46	2088	—

* The figures given in parentheses are on the substance partially dried, but not fully dried at 100° C.

It should be observed that the amounts of chlorophyll recorded are as stated, *relative*, and not actual; and the figures show the relative amounts for the individual members of each pair of experiments, and not the comparative amounts as between one set of experiments and another. It should further be stated that the chlorophyll determinations were kindly made by Dr. W. J. Russell, F.R.S., of London, in specimens collected at Rothamsted, whilst the wheat and barley were still green, and actively growing.

It will be seen, in the first place, that the separated leguminous herbage of hay contained a much higher percentage of nitrogen in its dry matter than the separated gramineous herbage; and that, with the much higher percentage of nitrogen in the leguminous herbage, there was also a much higher proportion of chlorophyll.

Next, it is to be observed that the wheat plant on plot 10a, manured with ammonium-salts alone, shows a much higher percentage of nitrogen than that of plot 7, with the same amount of ammonium-salts, but with mineral manure in addition. The high proportion of chlorophyll again goes with the high nitrogen percentage; but the last column of the table shows that on plot 10a, with ammonium-salts without mineral manure, with the high percentage of nitrogen and high proportion of chlorophyll in the green produce, there was eventually a very much less assimilation of carbon. The result is exactly similar in the case of the barley; plot 1a being manured with ammonium-salts alone, and plot 4a with the same ammonium-salts and mineral manure in addition.

It is evident that the chlorophyll formation has a close connection with the amount of nitrogen assimilated; but that the carbon assimilation is not in proportion to the chlorophyll formed, if there is not a sufficiency of the necessary mineral constituents available. No doubt there had been as much or more of both nitrogen assimilated, and chlorophyll formed, over a given area, where the mineral as well as the nitrogenous manure had been applied; the lower *proportion* of both in the dry matter being due to the greater assimilation of carbon, and consequent greater formation of non-nitrogenous substance.

The next point to consider is, what is the effect of the unrecovered amount of nitrogen on succeeding crops? This is illustrated by the results in the coloured columns of Table I (facing p. 7). In the table, mineral manure is indicated by blue, nitrogen as ammonium-salts by yellow, and a mixture of the two by green. Plot 5 has been manured continuously for thirty-two years with mineral manure alone; whilst plots 17 and 18 each received mineral manure, and a quantity of ammonium-salts containing 86 lbs. of nitrogen, alternately. Thus we are able, for every year, to compare a plot manured with minerals, succeeding a previous application of ammonium-salts, with a plot receiving mineral manure alone every year. It is seen that, in every case, the application of nitrogen has given a greatly increased yield, frequently doubling that of the plot with mineral manure alone. Again, in every case, the yield of the succeeding year, when the mineral manure was applied, was reduced approximately to that of the plot continuously treated with minerals alone. A glance down the alternately blue and yellow columns of plots 17 and 18, and a comparison with the blue column of plot 5, will bring these results strikingly to view. A comparison of the averages of the periods of four, eight, sixteen, and thirty-two years, of this treatment, clearly shows the essential identity of the results of the continuous and the alternate treatment with mineral manures. The averages for the thirty-two years show an increase in the yield of the mineral-manure years after ammonia, over the yield of plot 5, of only ⅝ of a bushel per acre per annum in a crop of between fifteen and sixteen bushels. The non-effect, or the absence, of residual nitrogen applied in the form of ammonium-salts, is evident. In other words, nitrogen as ammonium-salts applied in any one year is practically exhausted that year, in the crop or otherwise, leaving practically none for subsequent action.

Again, plot 16, for thirteen years, from 1852 to 1864 inclusive, received annually mixed mineral manure and ammonium-salts, containing a double quantity (172 lbs.) of nitrogen; and since that time, for nineteen years (1864–1883), it has been left unmanured. During the thirteen years of heavy manuring there was a large yield, in two cases exceeding

fifty bushels, with an average for the thirteen years of 39⅞ bushels. The first three years during which no manure was applied, the average yield was only 21⅛ bushels, a decrease of nearly one-half, followed in the succeeding periods of four years each by average yields of 17⅝, 12, 9⅝, and 13¾ bushels; against, for the corresponding periods on plot 3, continuously without manure, 13¾, 10⅝, 8⅛, and 12⅛ bushels. Or, taking the average of the nineteen years of yield without manure on plot 16, we have 14⅝ bushels, against, over the same years, 13⅞ bushels, on plot 5, with mineral manures only, since 1852, and 11⅝ bushels on plot 3, unmanured since 1839. It is fair to presume, moreover, that some of the greater yield of plot 16, from 1864–1883, over that of plot 3, is due to the residue of the mixed mineral manure, which, as will be seen further on, has some effect on succeeding crops.

If, as the above results have demonstrated, there is practically no residue from previous application of ammonium-salts, the question arises, What becomes of the nitrogen of the manure not taken up by the crop? This point is illustrated by the results given in Table V. The plots there tabulated all received the same amount of nitrogen in manure, with differing mineral manures, and they are given in the order of their average annual increased yield of nitrogen in the crops over plot 5, with mineral manure alone. The first column shows the estimated average annual increased yield of nitrogen per acre in the crops; the second, the estimated annual loss of nitrogen as nitric acid by drainage; the third, the estimated annual excess of nitrogen in the surface-soil over that on plot 5 with the mineral manure alone; and the last column shows the relation which that excess in the soil bears to 100 increased yield of nitrogen in the crops.

The plots were manured as follows

Plot 10—Amm.-salts = 86 lbs. N.
„ 11—Amm.-salts = 86 lbs. N., and superphosphate.
„ 12—Amm.-salts = 86 lbs. N., superphosphate and soda.
„ 13—Amm.-salts = 86 lbs. N., superphosphate and potash.
„ 14—Amm.-salts = 86 lbs. N., superphosphate and magnesia.
„ 7—Amm.-salts = 86 lbs. N., and mixed mineral manure.
„ 9—Nitrate of soda = 86 lbs. N., and mixed mineral manure.

TABLE V.

BROADBALK EXPERIMENTAL WHEAT-FIELD.

Estimated Nitrogen per acre per annum.

PLOTS.	In Crops over Plot 5.	Lost by Drainage over Plot 5.	In surface soil, 9 inches deep, over Plot 5.	Excess in surface soil to 100 increase in Crop.
	lbs.	lbs.	lbs.	lbs.
10	12.4	31.2	4.8	38.7
11	17.7	28.5	11.6	65.5
12	22.2	24.5	14.6	65.8
13	23.4	25.6	17.8	76.1
14	24.1	27.5	15.5	64.3
7	25.9	19.0	19.3	74.5
9	26.5	23.7	18.5	71.2

It is seen that the increased yield of nitrogen in the crops varied exceedingly with the same amount supplied in manure, according to the condition as to supply of mineral constituents. Plot 10, with the ammonium-salts alone, gives the smallest increased yield of nitrogen in the crop; and plots 7 and 9, with the most complete mineral manure, each more than twice as much; the other plots giving intermediate amounts.

The order of the estimated loss of nitrogen by drainage is almost the converse of that of the increased yield in the crops. Plot 10, which gives the least increased yield in the crop, shows the greatest loss by drainage; and plots 7 and 9, which yield the greatest increase in the crop, show the least loss by drainage.

The excess in the soils (over plot 5) is obviously much more in the order of the increased yield in the crops. Plot 10, with the least in the increase of crop, and the most in the drainage, shows the least excess in the soil; whilst plots 7 and 9, with the greatest increased yield in the crop, and the least loss by drainage, show the greatest excess in the soil.

It is clear, therefore, that whilst the excess in the soil has no direct relation to the amount supplied in the manure, it has a very obvious relation to the increased yield in the crop; in other words, to the amount of growth. The last column of the table brings this out more clearly. Excepting in the case of plot 10, with the ammonium-salts alone, there is a general uniformity in the proportion of the excess in the soil over plot 5 to the increased yield in the crop over plot 5; and the variations, such as they are, have an obvious connection with the conditions of growth. Thus plots 11, 12, and 14, all with a deficient supply of potash, show approximately equal proportions retained in the soil for 100 of increase in the crop. Plots 13, 7, and 9, again, all with liberal supplies of potash, show higher, but approximately equal, proportions retained in the surface-soil for 100 of increased yield in the crop.

Upon the whole, it is obvious that the relative excess of nitrogen in the soils of the different plots is little, if at all, due to the direct retention by the soil of the nitrogen of the manure, but it is almost exclusively dependent on the difference in amount of the residue of the crops—of the stubble and roots, and perhaps of weeds.

This leads to the consideration of the actual differences in the crop with equal nitrogen supply and different mineral supply. This is illustrated by the results in Table VI., which shows the effects of mineral manures alone, of ammonium-salts alone, and of ammonium-salts with different mineral manures.

TABLE VI.

Wheat grown for forty years in succession on the same land.
Broadbalk Field, Rothamsted.

Results showing the effects of Mineral Manures alone, and when used in addition to Ammonium-Salts.

Quantities per acre. Produce: Dressed Grain in bushels.

		400 lbs. Ammonium-Salts = 86 lbs. Nitrogen per acre per annum.						
	Mixed Mineral Manure alone.	Alone, 1852 and since. Previously Min. Man. 1844. Am.-Salts 1845–51.	Alone, 1852 and since. Previously Min. Man. 1844, '48 and '50. Am.-Salts 1845, '7, '8, '9 and '51.	And Superphosphate.	And Superphosphate and Sulphate of Soda.	And Superphosphate and Sulphate of Potash.	And Superphosphate and Sulphate of Magnesia.	And Superphosphate and Sulphates of Potash, Soda, and Magnesia.
Plot Nos.—	Plot 5	Plot 10a	Plot 10b	Plot 11	Plot 12	Plot 13	Plot 14	Plot 7
Harvests.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.	Bushels.
8 yrs. '44, '51	29	26	24½	28½	28½	27½	27¼	29¼
1852	16⅞	21⅞	22½	23¼	24⅝	24	24¾	26¾
1853	10⅛	10	15⅛	18⅛	22⅞	23	22⅝	23⅝
1854	24¼	34⅝	39¼	43⅞	45⅝	44⅞	44¾	45⅞
1855	18¼	20	28⅛	21¾	31¾	30¾	31⅝	33
1856	19½	24¼	27¾	31¼	33⅜	31⅝	34⅝	36⅝
1857	23¾	29½	34½	39⅛	43¾	43½	43⅜	44⅞
1858	18⅞	22⅝	27¾	32	37⅝	37¼	38½	39⅛
1859	20⅝	19	25⅛	27⅝	34¾	34½	34½	34⅝
1860	15⅞	15½	18⅝	22⅜	27⅝	26⅝	27¼	27¾
1861	15½	12⅜	16	24⅝	32⅜	34⅛	33½	35
1862	17¾	23½	24⅞	26⅜	33¾	32⅝	31¼	35⅜
1863	19⅝	39⅛	43⅝	45¾	54	53¼	54	53⅝
1864	16⅞	32½	36¼	36½	44⅝	43¼	41½	45¾
1865	14¼	25¾	30½	27⅝	34⅝	37½	36⅝	40¼
1866	13¼	26¼	28½	28	28¾	24¾	28	29⅞
1867	9¼	18½	19⅝	22½	24½	23⅞	22¾	22½
1868	17⅝	24¾	27¾	33½	39⅞	39¼	41¾	39⅞
1869	15¾	20¼	19½	22¼	27¼	27¼	27⅜	28⅝
1870	18⅞	21⅜	23¼	25¼	35¾	37	35¾	40⅜
1871	11⅞	10½	10	11	21½	30⅝	24¼	22⅞
1872	12¾	18	18¾	27⅞	29¼	29⅞	30⅜	29¾
1873	12¾	19⅝	20⅝	19¼	22⅞	23½	24½	22
1874	13	25⅞	27¼	32⅜	39½	37½	36⅝	39⅝
1875	9¾	12¾	14⅝	18	25¾	27½	26¼	25⅝
1876	10⅝	12½	14⅝	14⅝	19½	25½	22½	23⅝
1877	11⅝	17¼	18¼	17⅞	17¾	18¼	18½	19⅞
1878	14¾	27⅝	29⅞	29⅝	29¼	29½	32½	31¾
1879	5⅝	4	4⅝	11½	14	16	16¼	16¾
1880	17¾	10⅝	13⅛	25¾	29⅜	33	31	34½
1881	12¾	18¼	19¾	21½	23¾	28¼	27⅜	26⅝
1882	12½	23¾	26½	30⅜	34⅝	32½	34¾	35¾
1883	15¾	17⅞	18⅝	26⅝	30¾	34½	33⅝	36½
				AVERAGES.				
4 yrs. '52, '55	17⅝	21⅞	26¾	26¾	31¾	30⅝	30⅝	32¾
4 yrs. '56, '59	20¾	23⅞	28⅝	32½	37⅛	36⅝	37⅝	38⅝
4 yrs. '60, '63	17¾	22⅛	25¾	29⅞	37	36⅝	36¾	38
4 yrs. '64, '67	13⅝	25⅛	25⅝	28⅝	33	32¼	32¼	34⅜
4 yrs. '68, '71	16	19¼	20	23	30⅜	33⅜	32⅜	33⅜
4 yrs. '72, '75	12	18⅜	20¾	24⅝	29¼	29⅜	29⅜	29¼
4 yrs. '76, '79	10⅝	15¼	16⅞	18¼	20	22¼	22¼	22⅝
4 yrs. '80, '83	14¾	17⅛	19⅛	26	29⅝	31⅛	31⅝	33¼
8 yrs. '52, '59	19	22¾	27⅛	29⅝	34¾	33⅝	34¼	35⅝
8 yrs. '60, '67	15¾	24	27¼	29⅛	35	34⅜	34⅜	36¼
8 yrs. '68, '75	14	19	20⅜	23⅝	30	31⅜	30⅝	31
8 yrs. '76, '83	12⅝	16⅝	18⅛	22⅛	24⅞	27	27	28
16 yrs. '52, '67	17⅛	23⅝	27⅜	29⅜	34⅜	34	34⅜	35⅜
16 yrs. '68, '83	13⅝	17¾	19⅛	22⅝	27⅛	29¾	28⅜	29⅝
32 yrs. '52, '83	15¾	20⅛	23¼	26⅛	31	31⅜	31⅜	32⅜
Plot Nos.—	5	10a	10b	11	12	13	14	7

For the thirty-two years,—1852 to 1883 inclusive,—each of the eight differently manured plots received the same manure each year. I will only call special attention to the average yields over periods of sixteen and thirty-two years.

Plot 5, treated with mineral manure only, gave, during the first sixteen years, an average yearly yield of 17⅛ bushels per acre, during the second sixteen years 13⅜ bushels, and during the whole period of thirty-two years 15¼ bushels.

Plot 10a, treated with ammonium-salts only, gave, during the first sixteen years, an average yearly yield of 23⅜ bushels per acre, during the second sixteen years 17¾ bushels, and during the thirty-two years an average of 20⅛ bushels. Thus, ammonium-salts alone produced much more than mineral manure alone.

On plot 10b, previous to 1852,—in the years 1844, 1848, and 1850,—mineral manures had been applied, in the other years previous to 1852 (excepting in 1846, when it was unmanured), and subsequently, ammonium-salts only. The effect of the residue of the previously applied mineral manures is apparent on comparison with the yields on 10a.

On plot 10b we find, during the first period of sixteen years, an average yearly yield of 27⅜ bushels per acre, against 23⅜ bushels on 10a; during the second period of sixteen years 19⅛ bushels, against 17¾ on 10a; and during the thirty-two years, an average yearly yield of 23¼ bushels, against only 20⅛ on 10a.

Plot 11, with superphosphate but no potash, in addition to the ammonium-salts, gave, during the first sixteen years, an average yearly yield of 29⅜ bushels per acre, during the second sixteen years 22⅞ bushels, and during the thirty-two years 26⅛ bushels.

On plot 12, in addition to the ammonium-salts, superphosphate and sulphate of soda were applied; but potash had been applied prior to 1852. The first sixteen years produced an average yearly yield of 34⅜ bushels per acre, the second sixteen years of 27⅛ bushels, and the whole thirty-two years of 31 bushels.

On plot 13, the ammonium-salts, superphosphate, and sulphate of potash were applied, and the average annual produce was, over the first sixteen years 34 bushels, over the second sixteen years 29¼, and over the thirty-two years 31⅝ bushels.

On plot 14, besides the ammonium-salts and superphosphate, sulphate of magnesia was applied, and some potash had been applied prior to 1852. The average annual produce was, over the first sixteen years 34⅜ bushels, over the second sixteen years 28⅜ bushels, and over the thirty-two years 31⅜ bushels.

On plot 7, in addition to the ammonium-salts, superphosphate and the sulphates of potash, soda, and magnesia, were applied, and there was an average yearly yield, during the first sixteen years of 35⅜ bushels per acre, during the second sixteen years of 29⅛ bushels, and during the whole thirty-two years of 32¾ bushels.

Thus, not only the effect upon the yield of wheat of a direct supply, but of a residue from long previous applications of potash, is very noticeable. This is rendered more obvious by reference to the following table (VII.), in which the pounds per acre of potash and phosphoric acid removed during two periods of ten years each, in the total produce,

and in the grain alone, of the plots last referred to, and some others are given.

TABLE VII.

Potash and Phosphoric Acid in Grain, and in Total Produce.

Ten years, 1852–'61, and ten years, 1862–'71.

PER ACRE IN POUNDS.

PLOTS.	POTASH.				PHOSPHORIC ACID.			
	1852–'61.		1862–'71.		1852–'61.		1862–'71.	
	In Total Produce.	In Grain.	In Total Produce.	In Grain.	In Total Produce.	In Grain.	In Total Produce.	In Grain.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
2	52.6	11.8	53.5	12 4	26.5	19.6	27.3	20 1
3	19.0	5.5	15.3	4.9	10.8	8.2	9.7	7.5
5	26.6	6.6	21.1	5.7	14.7	10.5	12.3	8.8
10a	27.2	7.1	23.1	7.7	13.0	9.6	13.4	10.4
10b	33.3	8.5	25.0	8.7	16.0	12.2	14 8	12.0
11	30.9	9.3	26.0	8.8	19.8	14.9	18.0	13.6
12	45.4	11.4	37.8	11.4	23.2	17.7	21.8	17.0
13	53.2	11.3	55.2	12.2	22.9	17.7	23.3	18.2
14	49.8	11.3	39.1	11.6	22.9	17.9	22.4	17.6
7	56.0	11.9	53.0	12.3	23.8	18.4	23.4	18.5

I will illustrate this point by referring only to the potash. Plots 3, 10a, 10b, and 11, show a deficiency of potash in both grain and total produce compared with the amounts in the produce of plots 2, 12, 13, 14 and 7, on all of which there was a sufficiency, or more or less excess, of potash available. On comparison of these results with the manuring of the plots, we find that in every case the increase of potash in the total crop depends either on a direct annual potash supply, or on a residue from previous applications. The first ten years show more potash in the total produce with the direct supply (13 and 7) than with the residue (12 and 14); but the amount in the grain is essentially the same in each case. In the second ten years there is a greater difference in the amounts of potash in the total produce between the plots having the direct and those having only the residual supply; whilst there is scarcely any difference in the amounts in the grain, but such as it is, it is in accordance with the conditions of supply. Hence it is evident that whilst the plant in its vegetative stages assimilates according to the available supply,—it may be in excess of actual need,—if there is no deficiency, the composition of the final product—the seed—is essentially the same.

We have thus traced the effects of exhaustion, of full manuring, and of nitrogenous and non-nitrogenous manures, on one particular soil. It has been seen how very different is the effect of one and the same manuring in different seasons, but the real extent of this variation is more clearly brought out in Table VIII., which shows the best, the worst, and the average produce, over a period of thirty-two years, under very opposite conditions as to manuring.

TABLE VIII.

Wheat year after year on the same land. Broadbalk Field, Rothamsted.

Produce of the best season, 1863; the worst season, 1879; and average of 32 years, 1852–1883.

Plot No.	Description of Manures—Quantities per acre.	Dressed Grain per acre—Bushels.			
		Best Season, 1863.	Worst Season, 1879.	Difference.	Average 32 yrs. 1852–'83.
3	Unmanured	17¼	4¾	12½	13½
2	Farm-Yard Manure	44	16	28	33½
5	Mixed Mineral Manure, alone	19½	5½	14	15½
6	Mixed Min. Man. and 200 lbs. Amm.-Salts = 43 lbs. Nit.	39½	10½	29½	24½
7	Mixed Min. Man. and 400 lbs. Amm.-Salts = 86 lbs. Nit.	53½	16¼	37½	32¼
9	Mixed Min. Man. and 550 lbs. Nitrate Soda = 86 lbs. Nit.	55½	22	33½	36¼
8	Mixed Min. Man. and 600 lbs. Amm.-Salts = 129 lbs. Nit.	55¾	20½	35½	36¼

We will confine our attention to the amount of dressed grain per acre in bushels. The difference in yield of the various plots in the best and worst of the thirty-two seasons is very marked. The unmanured, the mineral manured, and the heavily nitrogenous manured plots, all suffered severely. In most cases the difference approaches, and in two cases (Plots 6 and 7, mixed mineral manure, together with 200 and 400 pounds of ammonium-salts, respectively furnishing 43 and 86 pounds of nitrogen) it actually exceeds the average produce of the plots. From these facts we see how easy it is to form wrong conclusions as to the effects of different manures, if experiments are conducted in only one season, or in only a few seasons, and if the characters of the seasons are not studied.

Not only season, but soil and locality must exercise an influence. The Rothamsted results are obtained on one description of soil, and in one locality only. Reference to the following table (IX.) shows the results obtained in experiments conducted at Rothamsted during the same eight years, but in two fields; at the same place in one field for thirty-two years; at Woburn, for seven years; at Holkham, Norfolk, for three years; and at Rodmersham, Kent, for four years. Thus, the experiments were made on very various soils, under various conditions from previous treatment, and in various seasons, yet the general characters of the results are accordant.

TABLE IX.

Results of Experiments on the growth of Wheat by different Manures, on different Soils, in different Localities, and in different Seasons.

MANURES. QUANTITIES PER ACRE.	DRESSED GRAIN PER ACRE—BUSHELS. AVERAGE ANNUAL RESULTS.					
	Rothamsted.			Woburn, Beds, 7 years. 1877–'83.	Holkham, Norfolk, 3 years. 1852–'54.	Rodmersham, Kent. 4 years. 1856–'59.
	8 years— 1856–'63.		32 years— 1852–'83.			
	Broadbalk Field.	Hoos Field.	Broadbalk Field.			
Unmanured	16	15	13½	15½	18	25½
Mixed Mineral Manure, alone	19	16½	15½	16½	19½	23½
Amm.-Salts, alone=86 lbs. N.	23½	26½	20½	23½ (1)	27½	31½
Mixed Mineral Manure, and Ammonium-Salts = 86 lbs. N.	38½	37½	32½	37½	32½	33½

(1) By Ammonium-Salts = only 43 lbs. N.

Not only is there general accordance in the character of the results in different localities, when the averages of a number of years are taken, but the non-effect of the residue from previous application of ammonium-salts is as marked in the sandy soil at Woburn as in the very different soil at Rothamsted. Reference to Table X. will illustrate this. Stackyard field, Woburn, received mineral manure, and ammonium-salts = 86 lbs. nitrogen, for five successive years. The field was then divided, one portion receiving the same manure as before, and the other the mixed mineral manure, but no nitrogen. In the next year, 1883, the portion which had received nitrogen in the previous year received mineral manures only, and conversely the other portion, which had received mineral manure only in 1882, received both mineral manure and ammonium-salts. It is seen that in each year, 1882 and 1883, the portion which received the nitrogenous manure yielded large crops (43⅞ and 45¾ bushels); whereas, the portion on which mineral manures alone succeeded ammonium-salts and large crops, yielded very small crops—13¼ and 17¼ bushels, respectively, against 14⅞ and 17¼ bushels on the plot where the same mineral manures were used year after year. It is thus seen that there was no available and effective residue where the ammonium-salts had previously been applied. It may be stated, however, that in 1884 there was notable effect from unexhausted residue of nitrogenous manure; the explanation probably being that there had been very little rain, and consequently very little loss by drainage during the winter of 1883–4.

TABLE X.

Wheat grown year after year on the same land.
Stackyard Field, Woburn.

Harvests.	Dressed Grain. Bushels.	
1877	43⅜	
1878	27	
1879	31¼	
1880	28⅝	
1881	43⅜	
1882	(1) 13¼	(2) 43⅞
1883	(2) 45⅝	(1) 17¼

(1) Mixed Mineral Manure alone. (2) Mix. Min. Man. and Ammonia-Salts = 86 lbs. N.

Produce, Imports, and Consumption of Wheat, in the United Kingdom.

Having illustrated the soil conditions necessary for the growth of wheat, it will be well to call attention to one practical application of these long-continued field experiments. For thirty-two years (1852–83) an estimate has been made of the average produce of wheat per acre in the United Kingdom, based upon the yield at Rothamsted on the unmanured, the farm-yard manured, and three of the artificially manured plots taken as one. From this the total yield of the country has been calculated; to this the imports have been added, and the quantity required for seed deducted, the final figure showing the total amount available for consumption, and from this the consumption per head of the population has been reckoned. It may be said at once that these results proved to be very near the truth. But the point of interest to a wheat-growing and wheat-exporting country like America is, the evidence which the results afford as to the constantly increasing requirements of a largely importing country like Great Britain.

The following table (XI.) shows that during the thirty-two years, 1852–3 to 1883–4, inclusive, the area under wheat in the United Kingdom has been reduced by about one-third. The average yield per acre is estimated at 28 bushels; but owing to recent bad seasons, the average for the whole period of thirty-two years was only 27 bushels, that for the first sixteen years having been 28¼, but that for the second sixteen years only 25¾. Thus there has not only been a reduction in area under cultivation, but in yield per acre, also; this, however, is probably temporary, whilst the reduction in area will doubtless continue.

TABLE XI.

Particulars of Home Produce, Imports, and Consumption of Wheat, in the United Kingdom—32 years, 1852–3 to 1883–4.

Harvest years, Sept. 1 to Aug. 31.	Estimated Home Produce.			Available for consumption.			Available for Consumption per head.		
	Area under Crop.	Average yield per Acre.	Total Home Produce.	Home Produce less 2¼ bush. per acre for Seed.	Imports less Exports.	Total.	From Home Produce.	From Imports.	Total.
	Acres.	Bush.	Quarters.	Quarters.	Quarters.	Quarters.	Bush.	Bush.	Bush.
1852–3	4.058.731	23⅞	11.574.982	10.433.464	5.902.000	16.335.464	3.03	1.71	4.74
1853–4	4.013.963	20⅞	10.466.473	9.337.546	6.092.000	15.429.546	2.70	1.76	4.46
1854–5	4.036.969	34¾	17.563.140	16.427.742	2.983.000	19.410.742	4.73	0.85	5.58
1855–6	4.076.447	27⅝	13.922.801	12.776.300	3.265.000	16.041.300	3.65	0.93	4.58
1856–7	4.213.651	27	14.192.543	13.007.453	4.112.584	17.120.037	3.70	1.16	4.86
1857–8	4.185.974	33⅛	17.321.221	16.143.915	5.795.687	21.939.602	4.56	1.63	6.19
1858–9	4.131.822	31⅛	16.309.949	15.147.874	4.555.670	19.703.544	4.24	1.28	5.52
1859–60	4.019.725	26⅛	13.135.124	12.004.575	4.516.332	16.520.907	3.34	1.25	4.59
1860–1	3.992.657	22⅛	11.078.948	9.956.012	10.023.968	19.979.980	2.75	2.77	5.52
1861–2	3.898.177	25¼	12.271.546	11.175.183	9.099.455	20.274.638	3.06	2.49	5.55
1862–3	3.823.947	29¼	13.957.554	12.882.069	9.205.086	22.087.155	3.51	2.51	6.02
1863–4	3.698.629	38¾	17.922.048	16.881.807	6.991.270	23.873.077	4.57	1.89	6.46
1864–5	3.685.493	35¼	16.216.328	15.179.783	5.500.705	20.680.488	4.08	1.48	5.56
1865–6	3.646.691	30⅝	13.975.936	12.950.305	7.313.026	20.263.331	3.47	1.95	5.42
1866–7	3.649.584	25⅛	11.485.091	10.458.645	7.633.033	18.091.678	2.78	2.02	4.80
1867–8	3.628.910	21	9.566.522	8.545.890	9.015.543	17.561.433	2.25	2.38	4.63
1868–9	3.937.275	34	16.733.419	15.626.060	7.719.304	23.345.364	4.09	2.02	6.11
1869–70	3.976.147	27	13.419.496	12.301.205	9.921.526	22.222.731	3.20	2.58	5.78
1870–1	3.761.457	30	14.105.464	13.047.554	8.008.839	21.056.393	3.33	2.05	5.38
1871–2	3.818.848	24	11.456.544	10.382.493	9.316.600	19.699.093	2.62	2.35	4.97
1872–3	3.827.146	24	11.481.438	10.405.053	12.291.463	22.696.516	2.60	3.07	5.67
1873–4	3.658.815	22⅝	10.290.417	9.261.375	11.301.316	20.562.691	2.29	2.80	5.09
1874–5	3.821.655	29¼	13.972.926	12.898.085	11.705.255	24.603.340	3.16	2.87	6.03
1875–6	3.503.709	22⅞	10.018.418	9.033.000	13.860.079	22.893.079	2.19	3.36	5.55
1876–7	3.114.555	25	9.732.984	8.857.015	12.107.294	20.964.309	2.13	2.91	5.04
1877–8	3.311.859	26⅛	10.970.533	10.039.073	14.408.628	24.447.701	2.38	3.42	5.80
1878–9	3.372.590	30	12.647.213	11.698.672	14.145.649	25.844.321	2.75	3.32	6.07
1879–80	3.047.752	15⅝	5.905.020	5.047.840	16.409.933	21.457.773	1.17	3.82	4.99
1880–1	3.057.784	24⅛	9.364.464	8.504.462	16.182.210	24.686.672	1.95	3.72	5.67
1881–2	2.960.066	24	8.880.198	8.047.679	17.200.108	25.247.787	1.83	3.91	5.74
1882–3	3.157.924	25⅝	10.115.225	9.227.059	19.982.162	29.209.221	2.08	4.50	6.58
1883–4	2.707.949	28	9.477.822	8.616.211	15.815.878	24.432.089	1.92	3.53	5.45
AVERAGES.									
4 yrs. '52–'56	4.046.528	26⅛	13.381.849	12.243.763	4.560.500	16.804.263	3.53	1.31	4.84
4 yrs. '56–'60	4.137.793	29⅛	15.239.709	14.075.954	4.745.068	18.821.022	3.96	1.33	5.29
4 yrs. '60–'64	3.853.352	24⅞	13.807.524	12.723.768	8.829.945	21.553.713	3.47	2.42	5.89
4 yrs. '64–'68	3.652.670	28	12.810.969	11.783.656	7.365.577	19.149.233	3.14	1.96	5.10
4 yrs. '68–'72	3.873.432	28¾	13.928.731	12.839.328	8.741.567	21.580.895	3.31	2.25	5.56
4 yrs. '72–'76	3.702.831	24⅝	11.440.800	10.399.378	12.289.528	22.688.906	2.56	3.02	5.58
4 yrs. '76–'80	3.211.689	24¼	9.813.938	8.910.650	14.267.876	23.178.526	2.11	3.37	5.48
4 yrs. '80–'84	2.970.931	25½	9.459.427	8.598.853	17.295.090	25.893.943	1.95	3.86	5.81
8 yrs. '52–'60	4.092.160	28	14.310.779	13.159.859	4.652.784	17.812.643	3.74	1.32	5.06
8 yrs. '60–'68	3.753.011	28½	13.309.247	12.253.712	8.097.761	20.351.473	3.30	2.19	5.49
8 yrs. '68–'76	3.788.131	26⅝	12.684.765	11.619.353	10.515.548	22.134.901	2.94	2.63	5.57
8 yrs. '76–'84	3.091.310	24⅞	9.636.682	8.754.751	15.781.483	24.536.234	2.03	3.64	5.67
16 yrs. '52–'68	3.922.586	28¼	13.810.013	12.706.785	6.375.273	19.082.058	3.53	1.75	5.28
16 yrs. '68–'84	3.439.721	25¾	11.160.724	10.187.052	13.148.515	23.335.567	2.48	3.14	5.62
32 yrs. '52–'84	3.681.153	27	12.485.369	11.446.919	9.761.894	21.208.813	3.00	2.45	5.45

The great increase of population which has taken place within the period covered by the table has, of course, necessitated greatly increased consumption, and the comparison of the home production and the foreign importation, for successive periods, becomes of much interest. The table shows that the average annual consumption over the four successive periods of eight years each, increased as follows:

1852–3 to 1859–60,	Annual Consumption,	17,812,643	quarters.
1860–1 to 1867–8,	„ „	20,351,473	„
1868–9 to 1875–6,	„ „	22,134,901	„
1875–6 to 1883–4,	„ „	24,536,234	„

These amounts were supplied from home produce and importation as follows:

	HOME PRODUCTION.		IMPORTATION.	
1852–3 to 1859–60,	13,159,859	quarters	4,652,784	quarters.
1860–1 to 1867–8,	12,253,712	„	8,097,761	„
1868–9 to 1875–6,	11,619,353	„	10,515,548	„
1875–6 to 1883–4,	8,754,751	„	15,781,483	„

Thus, over the first eight years, only one-fourth of the wheat consumed was obtained from foreign sources, whilst over the last eight years, nearly two-thirds of the entire consumption were imported. It is probable that the home produce will still decline, consequent chiefly on reduction of area under cultivation; whilst with increase of population, imports must increase, and doubtless our supplies will be largely drawn from this continent.

Produce of Wheat and Indian Corn per acre, in the United States.

It has been stated that, excluding recent bad seasons, the average yield of wheat per acre of the old arable soils of Great Britain, is twenty-eight bushels. Comparing this yield with that of the United States, as shown in Table XII., we find, on the authority of the U.S. Census Bureau, that the general average of localities and years is 11.9 bushels per acre; a yield which is not equal to that of the continuously unmanured plot at Rothamsted, and which is considerably less than half the average yield of Great Britain under ordinary cultivation. This may be partly due to a shorter period of growth, and to rapid maturing, or in some localities to deficiency of rain; but it is probably largely also due to want of sufficient labour to clean the land, and to consequent luxuriance of weeds.

Referring to the table, we find the general averages of the different sections of the States ranging from 15.1 bushels per acre in New England, to 7.3 bushels in the South Atlantic and Eastern Gulf States. Even the North-west and Minnesota, including much prairie land, give very meagre average produce for such rich soil. So long as wheat is grown on such lands under the conditions frequent, and indeed almost inevitable, in the case of new settlement,—that is, growing it year after year, with deficient cultivation, luxuriance of weeds, and the burning of the straw,—only low yields per acre can be expected. The result is due to the fact that, under such conditions, fertility is cheap and labour dear. But with increased density of population, more mixed agriculture must

be adopted. Stock must be kept, the farm kept freer from weeds, the straw used instead of being burnt, and the manure from it, and from the consumed food, returned to the land. Then, and not till then, will the fertility of the rich prairie soils be conserved, and not wasted, as is too often the case under the necessities of the first breaking up, and the sparse settlement, of the country. That your rich prairie soils can, and should, yield more produce than they do, is clear from the high yields obtained occasionally, under favourable conditions of cultivation.

TABLE XII.

Average yield per acre of Wheat and Indian Corn in the United States.

(From Signal Service Reports.)

Six years—1875–1880.

	1875	1876	1877	1878	1879	1880	Gl. Av.
WHEAT—BUSHELS.							
New England	16.1	13.9	16.8	15.3	15.0	13.3	15.1
Middle States	10.6	12.3	13.2	14.0	13.4	14.5	13.0
South Atlantic States	7.5	6.8	9.0	6.5	8.0	6.2	7.3
East Gulf States	9.0	6.7	7.2	7.1	8.1	5.6	7.3
West Gulf States	14.8	11.5	11.1	13.2	7.7	7.7	11.0
Tennessee and Ohio Valley	9.5	10.5	12.8	13.0	16.3	14.1	12.7
Upper Lake Region	13.7	10.2	16.1	15.2	15.8	13.5	14.1
North West	7.5	9.5	14.8	12.2	13.1	12.5	11.6
Minnesota	17.0	8.5	18.5	12.0	12.3	13.2	13.6
California	11.0	13.0	9.5	17.0	14.0	16.0	13.4
Average	11.7	10.3	12.9	12.6	12.4	11.7	11.9
INDIAN CORN—BUSHELS.							
New England	34.0	35.8	35.9	36.5	32.2	32.9	34.6
Middle States	32.2	29.2	28.7	28.7	29.4	32.9	30.2
South Atlantic States	12.0	11.5	11.3	11.4	10.7	10.2	11.2
East Gulf States	15.0	13.3	13.2	12.1	14.3	13.4	13.6
West Gulf States	21.4	23.2	22.6	24.2	15.9	24.0	21.9
Tennessee and Ohio Valley	32.1	31.4	29.4	29.2	31.9	29.7	30.6
Upper Lake Region	27.0	31.6	23.3	37.4	38.1	36.5	32.3
North West	35.7	28.7	31.2	31.1	36.2	30.8	32.3
Minnesota	29.2	25.4	29.0	38.1	35.0	35.0	32.0
California	36.3	33.0	30.0	34.5	28.0	32.0	32.3
Average	27.5	26.3	25.5	28.3	27.2	27.7	27.1

Turning to Indian Corn, Table XII. shows that the yield of that cereal is very much higher than that of wheat; and the yield of nitrogen per acre in those corn crops would doubtless be much greater than in the wheat crops of the same localities. This is probably in part due to the high condition of the soil under which the crop is generally grown, corn generally following clover in the rotation. It is, however, doubtless in part due to the growth of corn extending much further into the late summer and autumn, the period during which nitrification is the most active in the soil, and when therefore the supply of nitrates to the plant will be greater under the same conditions of soil than in the case of wheat. This would be a very interesting subject for investigation, in the field and in the laboratory, tracing the nitrogen at various periods in the soil, in the plant, and in the drainage waters.

Produce of various crops per acre, in Manitoba.

The following table (XIII.) gives estimates of the yield of various crops on some Manitoba prairie soils:

TABLE XIII.

Estimates of the yield of various Crops in Manitoba.

Summary of Statistical Returns—seven years, 1876–1882.

Quantities in bushels per acre.

	1876	1877	1878	1879	1880	1881	1882	General Average.
Wheat	32	27	26	27	29	30	32	29
Barley.....	42	41	36	38	41	40	37	39
Oats.....	51	60	60	58	58	59	51	57
Rye.....	—	30	30	40	40	35	—	35
Peas	32	32	34	32	38	38	—	34
Potatoes.....	229	304	308	302	318	320	278	294

The above estimates are founded on the reports of numerous farmers, and it is seen that the average yield of wheat for seven years (1876–1882) is assumed to be twenty-nine bushels. This is, however, doubtless too high, even for exclusively virgin prairie soils, under the condition of cultivation incident to new settlement; and the result is probably accounted for by the fact that the records come chiefly from the more intelligent and better farmers. From returns since supplied to me from the Department of Agriculture at Ottawa, the average produce of wheat in Manitoba was, in 1880, 20.1 bushels, and in 1882, 24.0 bushels, instead of 29 and 32 bushels as above; whilst the average produce in 1883 is estimated at 21.8 bushels.

Amounts of Nitrogen and Carbon in various Soils.

In connection with this subject of the average yield of wheat of different countries, it will be of interest to contrast the condition of soils of very different history, as to their percentage of nitrogen, and, so far as we are able, of carbon also.

Table XIV. (see next page) shows the characters in these respects of exhausted arable soils, of newly laid down pasture, and of old pasture soils, at Rothamsted; of some other old arable soils; of some Illinois and Manitoba prairie soils; and lastly, of some very rich Russian soils.

From these results there can be no doubt that a characteristic of a rich virgin soil, or of a permanent pasture surface-soil, is a relatively high percentage of nitrogen and of carbon, and a high relation of carbon to nitrogen. On the other hand, a soil that has long been under arable culture is much poorer in these respects; whilst an arable soil under conditions of known agricultural exhaustion shows a very low percentage of nitrogen and of carbon, and a low relation of carbon to nitrogen.

Finally, it has been maintained by some that a soil is a laboratory, and not a mine. But not only the facts ascertained in our own and in other investigations, but the history of agriculture throughout the world, so far as we know it, clearly show that a fertile soil is one which has accumulated within it the residue of ages of previous vegetation, and that it becomes infertile as this residue is exhausted; and enormous as are the accumulations in the prairie lands of the American continent, it it still desirable to postpone, rather than to accelerate, the time of their exhaustion.

TABLE XIV.

Nitrogen and Carbon in various soils.

	Date of Soil Sampling.	(1) In Dry Sifted Soil.			Authority.
		Nitrogen.	Carbon.	Carbon to 1 Nitrogen.	
ROTHAMSTED ARABLE AND GRASS SOILS.					
		Per cent.	Per cent.	Per cent.	
Roots, 1843–'52; Barley, 1853–'5; Roots, 1856–'69; Mineral Manures	April, 1870	0.0934	.....	.....	Rothamsted.
Wheat, 1843–'4, and each year since; Mineral Manures	October, 1865	0.1119	1.039	9.3	,,
	October, 1881	0.1012	1.079	10.7	,,
Barley, 1852, and each year since; Mineral Manures	March, 1868	0.1202	.....	.....	,,
	March, 1882	0.1124	1.154	10.3	,,
Arable laid down to grass (Ten-acres), Spring, 1879	February, 1882	0.1235	.....	.....	,,
Arable laid down to grass (Barn-field), Spring, 1874	February, 1882	0.1509	.....	.....	,,
Arable laid down to grass (Apple-tree field), Spring, 1863	November, 1881	0.1740	.....	.....	
Arable laid down to grass (Dr. Gilbert's meadow), Spring, 1858	January, 1879	0.2057	2.412	11.7	,,
Arable laid down to grass (High-field), Spring (?), 1838	September, 1878	0.1943	2.403	12.4	,,
Very old grass land (The Park)	Feb. & March, 1876	0.2466	3.377	13.7	,,
VARIOUS ARABLE SOILS IN GREAT BRITAIN.					
Mr. Prout's Farm; Broadfield—surface	.....	0.170	.....	.....	Voelcker.
Mr. Prout's Farm; Blackacre—surface	.....	0.107	.....	.....	,,
Mr. Prout's Farm; Whitemoor—surface	.....	0.171	.....	.....	,,
Wheat Soil—Midlothian	.....	0.22	.....	.....	Anderson.
,, East Lothian	.....	0.13	.....	.....	,,
,, Perthshire	.....	0.21	.....	.....	,,
,, Berwickshire	.....	0.14	.....	.....	,,
Red Sandstone Soil—England	.....	0.18	.....	.....	Voelcker.
UNITED STATES AND CANADIAN PRAIRIE SOILS.					
Illinois, U. S., No. 1	.....	0.30	.....	.....	Voelcker.
,, ,, No. 2	.....	0.26	.....	.....	,,
,, ,, No. 3	.....	0.33	.....	.....	,,
,, ,, No. 4	.....	0.34	.....	.....	,,
Portage la Prairie, Manitoba—surface	.....	0.247	.....	.....	Rothamsted.
Saskatchewan district, N. W. Territory—surface	.....	0.303	.....	.....	,,
Forty miles from Fort Ellice, N. W. Territory—surface	.....	0.250	.....	.....	,,
Niverville, Manitoba—1st 12 inches	.....	0.261	3.42	13.1	Rothamsted.
Brandon ,, ,,	.....	0.187	2.66	14.2	,,
Selkirk ,, ,,	.....	0.618	7.58	12.3	,,
Winnipeg ,, ,,	.....	0.428	5.21	12.2	,,
RUSSIAN SOILS.					
No. 1—12 inches	.....	0.607	.....	.....	C. Schmidt.
No. 2— 8 ,,	.....	0.467	.....	.....	,,
No. 3— 5 ,,	.....	0.188	.....	.....	,,
No. 4— 6 ,,	.....	0.130	.....	.....	,,
No. 5—11 ,,	.....	0.305	.....	.....	,,
No. 6—17 ,,	.....	0.281	.....	.....	,,
No. 7— 9 ,,	.....	0.409	.....	.....	,,

(1) Calculated on soil dried at 100 C.

NOTE ON SOME CONDITIONS OF

THE DEVELOPMENT AND THE ACTIVITY

OF

CHLOROPHYLL

BY

PROFESSOR J. H. GILBERT, LL.D., F.R.S.

Abstract of a Paper read at the Meeting of the British Association for the Advancement of Science, Aberdeen, 1885

Printed by

SPOTTISWOODE & CO., NEW-STREET SQUARE, LONDON

1885

Note on some Conditions of the Development, and of the Activity, of Chlorophyll. *By* Professor J. H. GILBERT, *LL.D., F.R.S.*

All who are accustomed to observe vegetation must have been struck with the great variety of shades of green which the foliage of different plants presents. Without pretending to generalise further, it may be stated that, at any rate so far as our common agricultural plants are concerned, they show somewhat characteristic shades of colour, according to the Natural Order to which they belong—the Leguminosæ differing from the Gramineæ, the Cruciferæ, the Chenopodiaceæ, and so on. But the same description of plant will exhibit very characteristic differences, not only at different stages of growth, but at the same stage in different conditions of luxuriance, as affected by the external conditions of soil, season, manuring, &c., but especially under the influence of different conditions as to manuring.

The Rothamsted Field experiments have afforded ample opportunity for observations of this kind; and it has been quite evident that, in a series of comparable experiments with the same crop, depth of green colour by no means necessarily implied a finally greater amount of carbon assimilation; whilst we have long ago experimentally proved that the deeper colour was associated with relatively high percentage of nitrogen in the dry or solid substance of the herbage; and this obviously means a lower relation of carbon to nitrogen.

Mentioning these facts to Dr. W. J. Russell, who has devoted so much attention to the subject of chlorophyll, he kindly undertook to make comparative determinations of the amounts of chlorophyll in parallel specimens, in which we were to determine the percentages of dry matter and of nitrogen. Accordingly, in June 1882, during the period of active vegetation, Dr. Russell spent a day at Rothamsted for the purpose of collecting appropriate samples, which were taken from several differently manured plots of meadow-grass, wheat, barley and potatoes, respectively.

The following table gives the results of some of these experiments; namely, the percentages of nitrogen, and the relative amounts of chlorophyll, in the separated gramineous and the separated leguminous plants in the mixed herbage of grass land; in specimens of wheat grown by a purely nitrogenous manure, and by the same nitrogenous manure with a full mineral manure in addition; and in specimens of barley grown by a purely nitrogenous manure, and by a mixture of the same nitrogenous manure and mineral manure in addition. It is to be borne in mind that the specimens were collected while the plants were still quite green, and actively growing. It should be further explained that the amounts of chlorophyll recorded are, as stated in the table, relative and not actual; that is to say, the figures show the relative amounts for the individual members of each pair of experiments, and not the comparative amounts as between one set of experiments and another.

It will be seen in the first place that the separated leguminous herbage of hay contained a much higher percentage of nitrogen in its dry substance than the separated gramineous herbage; and that, with the much higher percentage of nitrogen in the leguminous herbage, there was also a much higher proportion of chlorophyll. Under comparable conditions, however, the Leguminosæ eventually maintain a much higher relation of nitrogen to carbon than the Graminesæ, in other words, in their case carbon is not assimilated in so large a proportion to the nitrogen taken up.

Next, it is to be observed that the wheat plants manured with ammonium salts alone show a much higher percentage of nitrogen than those manured with the same amount of ammonium salts, but with mineral manure in addition. The high proportion of chlorophyll again goes with the high nitrogen percentage; but the last column of the table shows that, with the ammonium salts without mineral

RELATION BETWEEN NITROGEN ACCUMULATION, CHLOROPHYLL FORMATION, AND CARBON ASSIMILATION.

The figures in parentheses represent determinations in the not fully dried substance).

	Nitrogen per cent. in dry substance	Relative amounts of Chlorophyll	Carbon assimilated per acre per annum	
			Actual	Difference
HAY.			lbs.	lbs.
Gramineæ . . .	1·190	0·77		
Leguminosæ . . .	2·478	2·40		
WHEAT.				
Ammonium salts only .	(1·227)	2·00	1,398	- 824
Ammonium salts and mineral manure . . .	(0·566)	1·00	2,222	
BARLEY.				
Ammonium salts only .	(1·474)	3·20	1,403	- 685
Ammonium salts and mineral manure . . .	(0·792)	1·46	2,088	

manure with the high percentage of nitrogen, and the high proportion of chlorophyll, in the dry substance of the green produce, there is eventually a very much less assimilation of carbon. The result is exactly similar in the case of the barley. The plants manured with ammonium salts alone showing the higher percentage of nitrogen, and the higher proportion of chlorophyll, but eventually a much lower assimilation of carbon.

It is evident that the chlorophyll formation has a close connection with the amount of nitrogen assimilated, but that the carbon assimilation is not in proportion to the chlorophyll formed, if there be not a sufficiency of the necessary mineral constituents available. No doubt there had been as much, or more, of both nitrogen assimilated, and chlorophyll formed, over a given area, where the mineral as well as the nitrogenous manure had been applied, the lower proportion of both in the dry matter being due to the greater assimilation of carbon and consequent greater formation of non-nitrogenous substances.

It is of interest to observe, that these results of experiments in the field are perfectly consistent with those obtained by vegetable physiologists in the laboratory; they having found that the presence of certain mineral or ash-constituents, and especially that of potassium, is essential for the assimilation of carbon, no starch being formed in the grains of chlorophyll without the aid of that substance. Sachs says, 'Potassium is as essential for the assimilating activity of chlorophyll as iron for its production.'

PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
LONDON

ON THE

VALUATION

OF

UNEXHAUSTED MANURES.

BY

SIR JOHN BENNET LAWES, BART., LL.D., F.R.S.,

AND

JOSEPH HENRY GILBERT, LL.D., PH.D., F.R.S.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1886.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.
VOL. XXI.—S. S. PART II.

ON THE

VALUATION OF UNEXHAUSTED MANURES.

We have been requested by the Chemical Committee of the Royal Agricultural Society to draw up a Table of the composition and value of the manure obtained by the consumption of the food-stuffs in ordinary use on the farm. About twenty-five years ago we published a Table showing the average composition, per cent., and per ton, of the chief feeding-stuffs, and other agricultural products; and we called attention to the fact that there must be great difference in the value of the manure according to the composition of the food consumed. Soon afterwards, a Table was published, showing the estimated money-value of the manure from the consumption of one ton of the various foods.

The Table of composition was founded, partly on the results of analyses made at Rothamsted, but in great part on the results of others, which had at that time been published; and having calculated the amounts of nitrogen, phosphoric acid, and potash, contained in one ton of the respective foods, we deducted the quantities of phosphoric acid and potash which we estimated would be contained in the increase in live-weight of the animal consuming it. But, in the case of the nitrogen, we deducted 10 per cent. from the amounts in a ton of the cakes and leguminous seeds, which contain high percentages of nitrogen, and 15 per cent. from the amounts in the foods which contain lower percentages of nitrogen. These amounts of nitrogen deducted, were reckoned to include, besides the nitrogen actually stored up in the increase in live-weight, some loss, but not to cover the losses that take place in the manure after it is voided by the animal. The nitrogen and phosphoric acid in the manure, as so calculated, were then valued at the prices at

which they could be purchased in Peruvian guano, and the potash at its market price at the time. The total manure-value of a ton of each food, as so arrived at, was published, but the data were not given.

Objections have, from time to time, been raised against the manure-values given in that Table. At the date of its publication, compensation for unexhausted manure was not the law of the land; and whatever opinions may be held as to the amount of the valuation in any particular case, or as to the valuations as a whole, there can be no doubt that the discussion of the subject has led to the general recognition of the fact that cattle-foods vary very greatly in their manure-value. So far a very important step has been gained.

Fifteen years elapsed before the Duke of Richmond carried through Parliament (in 1875) "The Agricultural Holdings Act" for the compensation to the tenant, for his unexhausted improvements. This Bill proved, however, to be practically inoperative, as its provisions were not compulsory.

At a meeting of the Council of the Royal Agricultural Society, held on November 3rd, 1875, the following resolution was adopted, on the motion of Mr. Randell:—

"That while under any circumstances it would be of the greatest importance to the members of the Society to prove by a series of experiments made under every variety of soil and climate how far the accuracy of 'The estimated value of manure obtained by the consumption of different articles of food,' as given by Mr. Lawes in his valuable contribution to the last Spring number of the 'Journal' of the Society, is confirmed by practical results, it becomes more especially important now that compensation to outgoing tenants for the unexhausted value of purchased food will become subject to arbitration.

"That it be referred to the Chemical Committee to consider in what way experiments may be conducted by practical farmers in different districts to demonstrate by this union of 'Practice with Science,' the actual manure-value of the kinds of food most extensively purchased—say the first four articles in Mr. Lawes' Table, with any others the Committee may select—the feeding value of each being also recorded."

At the meeting of the Council, held on February 2nd, 1876, the Chemical Committee reported with reference to the foregoing resolution as follows:—

"That, recognising the very great importance of the question submitted to them, they recommended the Council to extend the reference, so as to enable the Committee to obtain the opinion of practical and scientific witnesses as to how far the

knowledge we already possess of the fertilising properties of manures and feeding-stuffs, especially the latter, can be relied upon as a basis of valuation to be made under the compensation-clauses of the Agricultural Holdings Act; and, in the event of those witnesses considering our present knowledge on these subjects insufficient, as to the expediency of making experiments with those objects in view."

During the next four weeks the Chemical Committee examined a number of witnesses, and, at the close of the evidence, reported as follows:—

"The Committee have to report that they have fully considered the evidence taken by them on the subjects connected with Mr. Randell's motion.

"They find in the case of nearly all the witnesses examined a very decided opinion in favour of experiments to determine the manurial and feeding-value of cakes and other feeding-stuffs.

"It seems to the Committee that the primary condition of any experiments to be conducted under the auspices of the Royal Agricultural Society should be that of their being thoroughly reliable, and of their results adding to the amount of knowledge previously existing on the subject-matter of the experiments.

"While some of the witnesses appear to see no difficulty in carrying out practical experiments of the kind indicated by Mr. Randell, the strongest possible opinions were expressed by the scientific witnesses that, although some special information of local interest might be obtained from them, they would be, in the words of one of the witnesses, 'of no use whatever for establishing anything like a scientific basis or principle, which is so much needed when a general question, such as that of manure-value, comes into play.'

"But the difficulties and doubts as to the possibility of these experiments being carried out in a trustworthy manner are not confined to scientific witnesses. They are pointed out in the strongest manner by some of those most in favour of these so-called practical experiments, one of whom, indeed, suggests their being instituted at places like the Universities, Kew, or Cirencester, adding that he does not know a single person in the three counties with which he is connected to whom he could entrust them. Another witness considers they ought to be under the direction of the Society's Chemist and the Chemical Committee; while it was generally assumed that those who might be willing to undertake the experiments should be compensated for their trouble and expense.

"The question of expense is one which the Committee are

confident the Council would consider of comparatively little consequence, if adequate results were to be expected; but although fully appreciating the object of Mr. Randell's motion, and the great importance—especially with reference to valuations under the Agricultural Holdings Act—of adding to our knowledge of the value of artificial manures and feeding-stuffs, they feel they would only be justified in recommending experiments, the results obtained from which would be held, by a general concurrence of opinion, scientific and practical, to be thoroughly exhaustive and worthy of confidence.

"An opportunity for carrying out experiments has been offered to the Society by the Duke of Bedford, and the Committee now recommend that Mr. Lawes and Dr. Voelcker be requested to draw up a scheme for carrying on at Woburn such experiments as they, in communication with the Chemical Committee, may determine on, it being understood that the experiments, when decided upon, shall be wholly under the control of one or both of these gentlemen.

"Although not prepared at present to propose—as being instituted under the auspices of the Society—any other experiments than such as may be determined on under the above recommendation, the Committee are far from wishing to discourage experiments independently conducted by practical farmers, but, on the contrary, would be glad to assist them. Dr. Voelcker expresses himself as anxious that such experiments should be made, and gives instances of some that might furnish useful information. It is therefore suggested that it may be of advantage if Dr. Voelcker be requested to draw up the plan of one or more of such practical experiments as he thinks might bear instructive results, laying down for the guidance of such farmers as might like to try them the necessary instructions and rules for conducting them.

"With regard to the great advantage which, by the evidence of all the witnesses, there would be in the establishment of some one scale of valuation of unexhausted manures, which would be recognised and adopted generally in the country, the Committee found that none of the witnesses were unfavourable to Mr. Lawes' Tables of manure-value, if confirmed by direct experiment. One, indeed, of the most important witnesses expresses his own reliance altogether on it as it stands; while another says he should, in any case where there was no agreement, most certainly adopt Mr. Lawes' Table, modified by his own experience, and by considerations as to climate and soil.

"Inasmuch, however, as the evidence clearly shows that experiments instituted for the purpose, as suggested by

Mr. Randell's motion, of corroborating or modifying Mr. Lawes' conclusions as to the manurial value of cakes and feeding-stuffs should be carried on for several years, it appears to the Committee that, pending the completion of such experiments—should they be carried out—it is desirable for the Society to draw up and publish, with the assistance of Mr. Lawes and Dr. Voelcker, a schedule of the manurial value of these substances, based upon Mr. Lawes' Tables, and on any other evidence that may come under their consideration."

The liberal offer of the Duke of Bedford, referred to in the above report, to furnish the necessary land, and the funds required to carry out an investigation in regard to the manure-value of consumed cattle-foods, and other points, having been accepted, a series of experiments was at once arranged, and commenced as soon as possible, and they are still in progress. It would not be appropriate on the present occasion to enter into the consideration of the important additions to our knowledge which have accrued from those experiments. Nor need we here refer to the fact that the manure from cattle-foods of such widely different manure-value as decorticated cotton-cake and maize should have shown very little difference in the crops to which they were applied, any further than to say that the result was doubtless due to the condition of the land being, in both cases, high enough to yield approximately maximum crops.

It is doubtless the certainty that the Duke of Richmond's Act would be followed by one securing to the tenant compensation for his unexhausted improvements, that has led the cultivators of the soil to pay much more attention in recent years to the comparative value of the manure from the consumption of different descriptions of cattle-food; and it is remarkable that, coincidently with the results obtained at Woburn, which do not establish the superiority of the manure from decorticated cotton-cake over that from maize, it has become almost universally recognised by farmers that the manure from the consumption of the cakes in ordinary use has a higher value than that from the cereal grains.

It is true that when Chambers of Agriculture, or Farmers' Clubs, have agreed upon a basis for compensation in amicable arrangements, they have generally preferred to fix the scale in proportion to the cost of the food, rather than to its manure-value. They have, however, in the case of cakes, and even of the leguminous seeds, assigned a larger proportion of their cost as compensation than in that of the cereal grains. Thus, the fact that foods rich in nitrogen yield manures of higher value than those which are poor in that substance, is fully recognised.

A great advance has thus been made; and in discussing the question of the *unexhausted residue of manures*, upon which we now propose to enter, it is a great advantage to know that agriculturists are ready to accept it as an established fact that the chemical composition of a food affords a true indication of its manure-value. Further evidence of improved knowledge is to be found in the fact, that the relative market prices of different cattle-foods gradually approximate more nearly to what may be called their relative scientific values—that is, their values taking into account both their feeding- and their manure-value. For example, ten years ago the price of linseed-cake ranged from 12*l.* to 14*l.* per ton, whilst decorticated cotton-cake was hardly saleable at half the price; linseed-cake being more valued as food, and the greater manure-value of cotton-cake not being recognised. Now, however, the relative market prices of the two foods much more nearly represent their true relative values, taking both their food and their manure values into account.

The discussions which have taken place in connection with, and subsequent to, the passing of the "Agricultural Holdings Act of 1883," which gives to the tenant the right of property in his unexhausted manures, have afforded the means of ascertaining the general views of agriculturists on the subject; and although some exaggerated opinions have been put forward, common-sense views have, upon the whole, prevailed; and we are encouraged to believe that any carefully considered contribution to the solution of this most complicated and difficult question will be favourably received, and will not be without practical value.

The existence of *unexhausted fertility*, resulting from the consumption of cattle-foods, depends upon the fact that when organic matter, animal or vegetable, is applied to the soil as manure, its complete decay, and the complete liberation of its fertilising constituents, extend over a considerable period of time. Poor land cannot be suddenly brought into "*condition*" by the consumption on the farm of purchased foods. Nor can "*condition*," that is accumulated fertility, be at once withdrawn by suddenly stopping the use of the foods.

The Rothamsted field experiments afford numerous illustrations of such gradual accumulation, and only gradual exhaustion. It may take a great many years of unmanured cropping to exhaust the accumulation from a few years' application of dung, and to bring the land back to its original state. Even when rape-cake is applied for the continuous growth of corn-crops, a considerable unexhausted residue remains in the soil. The fact that such accumulation does take place cannot be disputed. But when we come to consider—of what the accumulation

consists, what is its amount, and what its money-value, the real difficulties of the problem to be solved become apparent.

Each individual food, when judiciously used in conjunction with others, contributes more or less to the increase of the animal consuming it; and the increase will carry away a certain amount of the constituents of the food. The remainder, which constitute the manure, will, in the first place, increase the produce of the crops to which it is applied; but it will also leave an unexhausted residue, the amount, and the money-value of which to the succeeding tenant, we have to endeavour to determine.

We must, then, in the first place, form an estimate of the amount of increase in live-weight of animals which a given quantity of each food will produce, and of the amount of manure-constituents which that increase will take from the food. Next, we must endeavour to estimate the increase in the crops, and the amount of constituents so removed. Lastly, the amount, and the value, of the manure-residue has to be estimated. This we have done in the case of a number of the foods, the composition, the original manure-value, and the unexhausted manure-value of which, are given in the Tables which follow. We have then decided upon a scale of reduction of the unexhausted manure-value from year to year, and in this way arrived at an estimate of the money-value of the residue accumulated over a period of eight years. Finally, having thus come to a conclusion as to the amount of what may be called the *compensation-value* of the accumulated residue, we have devised a simple method of calculation, starting from the *total*, or *original manure-value*, of the various foods—that is, from the value deducting the constituents in the increase in live-weight only, and reckoning the remainder at the prices at which they can be purchased in artificial manures.

I. Average Composition of Cattle Foods.

The first Table we have to call attention to shows the average composition, per cent. and per ton, of thirty-six different foods, so far as this is necessary for the purpose of manure-value calculations; that is, it gives the amount *per cent.* of dry matter, nitrogen, total mineral matter (ash), phosphoric acid, and potash, and the amounts *per ton* of the foods, of nitrogen, phosphoric acid, and potash. In some cases the figures are the same as in our original Table, published about twenty-five years ago, but in all cases more recent analyses have been had recourse to, and alterations have been made if it seemed desirable.

TABLE I.—AVERAGE COMPOSITION, PER CENT. and PER TON, of CATTLE-FOODS.

Foods.	Per Cent.					Per Ton.		
	Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Phosphoric Acid.	Potash.	Nitrogen.	Phosphoric Acid.	Potash.
	per cent.	per cent.	per cent.	per cent.	per cent.	lbs.	lbs.	lbs.
1. Linseed	90·00	3·60	4·00	1·54	1·37	80·64	34·50	30·69
2. Linseed-cake ..	88·50	4·75	6·50	2·00	1·40	106·40	44·80	31·36
3. Decorticated cotton-cake ..	90·00	6·60	7·00	3·10	2·00	147·84	69·44	44·80
4. Palm-nut cake	91·00	2·50	3·60	1·20	0·50	56·00	26·88	11·20
5. Undecorticated cotton-cake ..	87·00	3·75	6·00	2·00	2·00	84·00	44·80	44·80
6. Cocoa-nut cake	90·00	3·40	6·00	1·40	2·00	76·16	31·36	44·80
7. Rape-cake ..	89·00	4·90	7·50	2·50	1·50	109·76	56·00	33·60
8. Peas	85·00	3·60	2·50	0·85	0·96	80·64	19·04	21·50
9. Beans	85·00	4·00	3·00	1·10	1·30	89·60	24·64	29·12
10. Lentils	88·00	4·20	4·00	0·75	0·70	94·08	16·80	15·68
11. Tares (seed) ..	84·00	4·20	2·50	0·80	0·80	94·08	17·92	17·92
12. Indian corn ..	88·00	1·70	1·40	0·60	0·37	38·08	13·44	8·29
13. Wheat	85·00	1·80	1·70	0·85	0·53	40·32	19·04	11·87
14. Malt	94·00	1·70	2·50	0·80	0·50	38·08	17·92	11·20
15. Barley	84·00	1·65	2·20	0·75	0·55	36·96	16·80	12·32
16. Oats	86·00	2·00	2·80	0·60	0·50	44·80	13·44	11·20
17. Rice meal* ..	90·00	1·90	7·50	(0·60)	(0·37)	42·56	(13·44)	(8·29)
18. Locust beans*	85·00	1·20	2·50	..	..	26·88	..	..
19. Malt coombs ..	90·00	3·90	8·00	2·00	2·00	87·36	44·80	44·80
20. Fine pollard ..	86·00	2·45	5·50	2·90	1·46	54·88	64·96	32·70
21. Coarse pollard ..	86·00	2·50	6·40	3·50	1·50	56·00	78·40	33·60
22. Bran	86·00	2·50	6·50	3·60	1·45	56·00	80·64	32·48
23. Clover hay ..	83·00	2·40	7·00	0·57	1·50	53·76	12·77	33·60
24. Meadow hay ..	84·00	1·50	6·50	0·40	1·60	33·60	8·96	35·84
25. Pea straw ..	82·50	1·00	5·50	0·35	1·00	22·40	7·84	22·40
26. Oat straw ..	83·00	0·50	5·50	0·24	1·00	11·20	5·38	22·40
27. Wheat straw ..	84·00	0·45	5·00	0·24	0·80	10·08	5·38	17·92
28. Barley straw ..	85·00	0·40	4·50	0·18	1·00	8·96	4·03	22·40
29. Bean straw ..	82·50	0·90	5·00	0·30	1·00	20·16	6·72	22·40
30. Potatoes	25·00	0·25	1·00	0·15	0·55	5·60	3·36	12·32
31. Carrots	14·00	0·20	0·90	0·09	0·28	4·48	2·02	6·27
32. Parsnips	16·00	0·22	1·00	0·19	0·36	4·93	4·26	8·06
33. Mangel wurzels	12·50	0·22	1·00	0·07	0·40	4·93	1·57	8·96
34. Swedish turnips	11·00	0·25	0·60	0·06	0·22	5·60	1·34	4·93
35. Yellow turnips*	9·00	0·20	0·65	(0·06)	(0·22)	4·48	(1·34)	(4·93)
36. White turnips ..	8·00	0·18	0·68	0·05	0·30	4·03	1·12	6·72

* In the case of neither Rice-meal, Locust-beans, nor Yellow Turnips, have records of ash-analyses been found. For Rice-meal the same percentages of phosphoric acid and potash as in Indian Corn, and for Yellow Turnips the same as in Swedes, are provisionally adopted; but in all the Tables the assumed results are given in parentheses. For Locust Beans no figure has been assumed, and the columns are left blank.

Although the figures given in the Table (I., p. 10) may be taken as fairly indicating the *average* composition of the different foods, yet it must be understood that in the case of almost every one of the articles in the list, individual samples may vary even considerably from the average. In the case of foods which are manufactured, or imported, the percentage of dry matter is usually high. In the case of those which may be either imported or home-grown, the variations in the percentage of dry matter in different samples may be comparatively wide; it being, as a rule, distinctly higher in the imported articles, which could not be shipped unless in a drier condition than is usual with the home-grown product. In such cases, therefore, the imported food will probably contain a higher, or the home-grown one a lower, percentage of dry matter, than the average amount given in the Table. Even in the case of professedly ripened products, such as cereal grains and leguminous seeds, the character of the season will materially influence their condition of dryness; and the same remark applies, in a greater or less degree, to such matters as hays and straws. Succulent matters again, such as roots, vary very considerably according to season, and to condition of maturity.

So far as individual constituents are concerned, very similar reservations must be made; and especially is this so in the case of the nitrogen. Even with professedly ripened products, the percentage of nitrogen may vary considerably according to soil, manuring, climate or season, &c., but especially according to season; and this is the case in a less degree with the phosphoric acid, and the potash, of such articles. But in the case of imperfectly ripened products, such as hay, and in a much greater degree in that of still less evenly matured and more succulent ones, such as roots, the percentage of nitrogen may vary very materially, and that of the phosphoric acid and potash to some extent.

Whilst, therefore, the figures given in the Table may be taken as representing the fairly average composition of the different foods, they must be adopted or modified with judgment, having regard to the influence of the conditions of growth, maturity, preparation, or preservation, to which they have been subject. Fortunately, however, unless the variation from the standard composition adopted in the Table be considerable, indeed more than is usual, the effect on the estimates of manure-value will not be material; but they will obviously be much greater in the case of the nitrogen, than in that of either the phosphoric acid or the potash.

II. Total or Original Manure-value, of Consumed Cattle Foods.

Table II. (pp. 14–15), shows the method, and the results, of the calculation of the *total*, or *original manure-value* of the different foods, adopting as a basis their composition as given in Table I.

The first column of the Table (II.) shows the estimated amounts of each food required to give one part of fattening increase in live-weight of oxen or sheep; and the second column shows the amounts of such increase that would, accordingly, be yielded by the consumption of one ton of each food. It is obvious that some estimate of this kind must be made before we can reckon how much of the manure-constituents of the food are carried off by the animal-increase, and consequently how much will remain for manure. These columns may, however, be very seriously misleading, unless their real meaning be understood. Thus, if given without further explanation, it might be concluded that, by the exclusive consumption by oxen or sheep, of one ton of any of the different foods, the amount of fattening increase given in the second column of the Table would be produced. In other words, that if so given, a ton of linseed-cake would yield 373 lbs., a ton of oat-straw 124 lbs., or a ton of swedes 20½ lbs. of increase. What is meant is, that when any one of the foods is given in the judicious amount, and admixture with other foods, which experience shows to be beneficial, it may be estimated that one ton of the food so consumed will, approximately, contribute the amount of increase in live-weight stated.

This will be better understood by giving some explanation of the way in which the figures have been arrived at. In the case of a few typical foods, a number of feeding experiments were selected in which the mixtures given were comparatively simple, and the results fairly average; and the productive effect of the particular food has been calculated, by eliminating that of the associated food, or foods, as determined in the case of other experiments, the results of which have been calculated in the same way. For example—the quantity of clover-chaff required to produce one of increase in various experiments was determined as follows:—

	Clover-chaff to 1 increase.
Oxen—with Linseed-cake, Barley, Swedes, and Clover-chaff ..	13·0
Oxen— „ „ „ „ ..	14·3
Sheep—with Linseed-cake, Swedes, and Clover-chaff	14·7
Sheep—with Barley, Swedes, and Clover-chaff	13·4
Sheep— „ „ „ „	15·5
Mean ..	14·2

In a similar manner the productive effects of linseed, linseed-cakes, barley, beans, and swedes, each used in suitable admixture with other foods, have been estimated. Thus, the actual and comparative productive effects of a few characteristic foods have been approximately determined; and from these results the capacity of allied foods has been estimated, taking into consideration the relative amounts of digestible and indigestible constituents, which the foods to be compared on the average contain. It is in this way that the figures in the first and second columns of Table II. have been arrived at. It should be stated, however, that in the case of the straws no direct experimental data were at command, and their productive effects are estimated mainly on their recorded amounts of digestible constituents compared with those in hay, and they are more probably given too high than too low.

It is obvious that such estimates can be only approximately correct; but they are at any rate the best that existing knowledge renders it possible to make. It is pretty certain that the amounts of increase assumed to be produced are higher than those usually obtained. The amount estimated to be yielded by linseed-cake, for example, is certainly higher than would be obtained, when, as is sometimes the case, it is given in such excessive amount that much is voided by the animals undigested. On the other hand, the amounts of the different foods estimated to be required to give 1 part of increase are doubtless higher than would be so required, if as large a proportion of the constituents were digested and utilised as have been shown to be digestible in the German experiments on that subject. In those experiments the animals were for the most part kept on mere sustenance food, so that they would digest the maximum proportion of the constituents they received. In the case of fattening, however, especially with early maturity, the conditions are very different. The animal receives a greater or less excess of food, and not only voids proportionally more undigested, but may transform more than is fully utilised. It is, nevertheless, economy to give an excess within certain limits. The apparent waste is, in fact, more than counterbalanced. Thus, in the first place, the manure-value of the not utilised food still remains intact; but the real source of the economy is in the shortening of the time of feeding, and so, at the cost of some excess of food, saving the amount that would be expended in the mere sustenance of the animal in feeding for a longer period.

Trusting that, with these explanations, the figures will not be misunderstood, we may proceed to the consideration of the rest of the Table, only further remarking in regard to the estimates in

TABLE II.—SHOWING the DATA, the METHOD, and the RESULTS, of the ESTIMATIONS

Nos.	Description of Food.	Fattening Increase in Live-weight (Oxen or Sheep).		Nitrogen.						
				In Food.		In Fattening Increase (at 1·27 Per Cent.).		In Manure.		
		Food to 1 Increase.	Increase per Ton of Food.	Per Cent.	Per Ton.	From 1 Ton of Food.	Per Cent. of Total Consumed.	Total Remaining for Manure.	Nitrogen equal Ammonia.	Value of Ammonia at 6d. per lb.
			lbs.	per cent.	lbs.	lbs.	per cent.	lbs.	lbs.	£ s. d.
1	Linseed	5·0	448·0	3·60	80·64	5·69	7·06	74·95	91·0	2 5 6
2	Linseed-cake ..	6·0	373·3	4·75	106·40	4·74	4·45	101·66	123·4	3 1 8
3	Decorticated cotton-cake ..	6·5	344·6	6·60	147·84	4·38	2·96	143·46	174·2	4 7 1
4	Palm-nut cake	7·0	320·0	2·50	56·00	4·06	7·25	51·94	63·1	1 11 7
5	Undecorticated cotton-cake ..	8·0	280·0	3·75	84·00	3·56	4·24	80·44	97·7	2 8 10
6	Cocoa-nut cake	8·0	280·0	3·40	76·16	3·56	4·67	72·60	88·2	2 4 1
7	Rape-cake ..	(10)	(224)	4·90	109·76	2·84	2·59	106·92	129·8	3 4 11
8	Peas	7·0	320·0	3·60	80·64	4·06	5·03	76·58	93·0	2 6 6
9	Beans	7·0	320·0	4·00	89·60	4·06	4·53	85·54	103·9	2 11 11
10	Lentils	7·0	320·0	4·20	94·08	4·06	4·32	90·02	109·3	2 14 8
11	Tares (seed) ..	7·0	320·0	4·20	94·08	4·06	4·32	90·02	109·3	2 14 8
12	Indian corn ..	7·2	311·1	1·70	38·08	3·95	10·37	34·13	41·4	1 0 9
13	Wheat	7·2	311·1	1·80	40·32	3·95	9·80	36·37	44·2	1 2 1
14	Malt	7·0	320·0	1·70	38·08	4·06	10·66	34·02	41·3	1 0 8
15	Barley	7·2	311·1	1·65	36·96	3·95	10·69	33·01	40·1	1 0 1
16	Oats	7·5	298·7	2·00	44·80	3·79	8·46	41·01	49·8	1 4 11
17	Rice meal ..	7·5	298·7	1·90	42·56	3·79	8·91	38·77	47·1	1 3 6
18	Locust beans ..	9·0	248·9	1·20	26·88	3·16	11·76	23·72	28·8	0 14 5
19	Malt coombs ..	8·0	280·0	3·90	87·36	3·56	4·08	83·80	101·8	2 10 11
20	Fine pollard ..	7·5	298·7	2·45	54·88	3·79	6·91	51·09	62·0	1 11 0
21	Coarse pollard	8·0	280·0	2·50	56·00	3·56	6·35	52·44	63·7	1 11 10
22	Bran	9·0	248·9	2·50	56·00	3·16	5·64	52·84	64·2	1 12 1
23	Clover hay ..	14·0	160·0	2·40	53·76	2·03	3·78	51·73	62·8	1 11 5
24	Meadow hay ..	15·0	149·3	1·50	33·60	1·90	5·65	31·70	38·5	0 19 3
25	Pea straw ..	16·0	140·0	1·00	22·40	1·78	7·95	20·62	25·0	0 12 6
26	Oat straw ..	18·0	124·4	0·50	11·20	1·58	14·11	9·62	11·7	0 5 10
27	Wheat straw ..	21·0	106·7	0·45	10·08	1·36	13·49	8·72	10·6	0 5 4
28	Barley straw ..	23·0	97·4	0·40	8·96	1·24	13·84	7·72	9·4	0 4 8
29	Bean straw ..	22·0	101·8	0·90	20·16	1·29	6·39	18·87	22·9	0 11 6
30	Potatoes	60·0	37·3	0·25	5·60	0·47	8·39	5·13	6·2	0 3 1
31	Carrots	85·7	26·1	0·20	4·48	0·33	7·37	4·15	5·0	0 2 6
32	Parsnips	75·0	29·9	0·22	4·93	0·38	7·71	4·55	5·5	0 2 9
33	Mangel wurzels	96·0	23·3	0·22	4·93	0·30	6·09	4·63	5·6	0 2 10
34	Swedish turnips	109·1	20·5	0·25	5·60	0·26	4·64	5·34	6·5	0 3 3
35	Yellow turnips	133·3	16·8	0·20	4·48	0·21	4·69	4·27	5·2	0 2 7
36	White turnips	150·0	14·9	0·18	4·03	0·19	4·71	3·84	4·7	0 2 4

of the ORIGINAL MANURE-VALUE of CATTLE-FOODS after CONSUMPTION.

PHOSPHORIC ACID.							POTASH.							
In Food.		In Fattening Increase (at 0·86 Per Cent.).		In Manure.			In Food.		In Fattening Increase (at 0·11 Per Cent.).		In Manure.			Total Original Manure-value per Ton of Food Consumed.
Per Cent.	Per Ton.	From 1 Ton of Food.	Per Cent. of Total Consumed.	Total Remaining for Manure.	Value at 3d. per lb.		Per Cent.	Per Ton.	From 1 Ton of Food.	Per Cent. of Total Consumed.	Total Remaining for Manure.	Value at 2½d. per lb.		
per cent.	lbs.	lbs.	per cent.	lbs.	*s.*	*d.*	per cent.	lbs.	lbs.	per cent.	lbs.	*s.*	*d.*	£ *s.* *d.*
1·54	34·50	3·85	11·16	30·65	7	8	1·37	30·69	0·49	1·60	30·20	6	3	2 19 5
2·00	44·80	3·21	7·17	41·59	10	5	1·40	31·36	0·41	1·31	30·95	6	5	3 18 6
3·10	69·44	2·96	4·26	66·48	16	8	2·00	44·80	0·38	0·85	44·42	9	3	5 13 0
1·20	26·88	2·75	10·23	24·13	6	0	0·50	11·20	0·35	3·13	10·85	2	3	1 19 10
2·00	44·80	2·41	5·38	42·39	10	7	2·00	44·80	0·31	0·69	44·49	9	3	3 8 8
1·40	31·36	2·41	7·68	28·95	7	3	2·00	44·80	0·31	0·69	44·49	9	3	3 0 7
2·50	56·00	1·93	3·45	54·07	13	6	1·50	33·60	0·25	0·74	33·35	6	11	4 5 4
0·85	19·04	2·75	14·44	16·29	4	1	0·96	21·50	0·35	1·63	21·15	4	5	2 15 0
1·10	24·64	2·75	11·16	21·89	5	6	1·30	29·12	0·35	1·20	28·77	6	0	3 3 5
0·75	16·80	2·75	16·37	14·05	3	6	0·70	15·68	0·35	2·23	15·33	3	2	3 1 4
0·80	17·92	2·75	15·35	15·17	3	9	0·80	17·92	0·35	1·95	17·57	3	8	3 2 1
0·60	13·44	2·68	19·94	10·76	2	8	0·37	8·29	0·34	4·10	7·95	1	8	1 5 1
0·85	19·04	2·68	14·08	16·36	4	1	0·53	11·87	0·34	2·86	11·53	2	5	1 8 7
0·80	17·92	2·75	15·35	15·17	3	9	0·50	11·20	0·35	3·13	10·85	2	3	1 6 8
0·75	16·80	2·68	15·95	14·12	3	6	0·55	12·32	0·34	2·76	11·98	2	6	1 6 1
0·60	13·44	2·57	19·12	10·87	2	8	0·50	11·20	0·33	2·94	10·87	2	3	1 9 10
(0·60)	(13·44)	2·57	(19·12)	(10·87)	(2	8)	(0·37)	(8·29)	0·33	(4·00)	(7·96)	(1	8)	(1 7 10)
..	..	2·14	..	..	..		..	..	0·27	..	..	..		..
2·00	44·80	2·41	5·38	42·39	10	7	2·00	44·80	0·31	0·69	44·49	9	3	3 10 9
2·90	64·96	2·57	3·96	62·39	15	7	1·46	32·70	0·33	1·01	32·37	6	9	2 13 4
3·50	78·40	2·41	3·07	75·99	19	0	1·50	33·60	0·31	0·92	33·29	6	11	2 17 9
3·60	80·64	2·14	2·65	78·50	19	8	1·45	32·48	0·27	0·83	32·21	6	8	2 18 5
0·57	12·77	1·38	10·81	11·39	2	10	1·50	33·60	0·18	0·54	33·42	7	0	2 1 3
0·40	8·96	1·28	14·28	7·68	1	11	1·60	35·84	0·16	0·45	35·68	7	5	1 8 7
0·35	7·84	1·20	15·31	6·64	1	8	1·00	22·40	0·15	0·67	22·25	4	8	0 18 10
0·24	5·38	1·07	19·89	4·31	1	1	1·00	22·40	0·14	0·63	22·26	4	8	0 11 7
0·24	5·38	0·92	17·10	4·46	1	1	0·80	17·92	0·12	0·67	17·80	3	8	0 10 1
0·18	4·03	0·84	20·84	3·19	0	9	1·00	22·40	0·11	0·49	22·29	4	8	0 10 1
0·30	6·72	0·88	13·10	5·84	1	5	1·00	22·40	0·11	0·49	22·29	4	8	0 17 7
0·15	3·36	0·32	9·52	3·04	0	9	0·55	12·32	0·04	0·32	12·28	2	7	0 6 5
0·09	2·02	0·22	10·89	1·80	0	5	0·28	6·27	0·03	0·48	6·24	1	4	0 4 3
0·19	4·26	0·26	6·10	4·00	1	0	0·36	8·06	0·03	0·37	8·03	1	8	0 5 5
0·07	1·57	0·20	12·74	1·37	0	4	0·40	8·96	0·03	0·34	8·93	1	10	0 5 0
0·06	1·34	0·18	13·43	1·16	0	4	0·22	4·93	0·02	0·41	4·91	1	0	0 4 7
(0·06)	(1·34)	0·14	(10·78)	(1·20)	(0	4)	(0·22)	(4·93)	0·02	(0·34)	(4·91)	(1	0)	(0 3 11)
0·05	1·12	0·13	11·61	0·99	0	3	0·30	6·72	0·02	0·30	6·70	1	5	0 4 0

question, that the amount of the manure-constituents of the food carried off by fattening increase is under all circumstances so small that, for the purposes of our calculations of manure-value, even a considerable variation from the average amounts assumed to be taken up by the animal would affect the final result but little.

The next division of the Table (II., pp. 14–15), comprising seven columns, relates to the amount, and to the distribution, of the nitrogen of the foods. There are given—the amounts of it per cent., and per ton, as in Table I.; the actual amount estimated to be contained in the increase in live-weight of the animal consuming one ton of the food, and the percentage of the total nitrogen consumed which is so retained in the increase; the amount of the nitrogen of the food remaining for manure, the amount of ammonia to which it corresponds, and its money-value reckoned at 6*d.* per lb. of ammonia.

Throughout the calculations, we have assumed only fattening increase to be produced, and that this will contain 8 per cent. of nitrogenous substance, corresponding to 1·27 per cent. of nitrogen in the increase. It will be seen that, according to the figures, the only food in the list of which a ton is estimated to contribute more than 5 lbs. of nitrogen to the fattening increase is linseed, and that in the case of none of the cakes, or of the leguminous seeds, will 1 ton contribute 5 lbs. of nitrogen to the increase; whilst the amount is in several cases under 4 lbs. A ton of the cereal grains, or of their products (and locust beans), generally contributes under 4 lbs.; a ton of hay or straw less than half as much; and a ton of roots very much less still.

To put it in another way: of the total nitrogen consumed in the foods rich in that substance, such as the cakes and the leguminous seeds, there is generally less than 5 per cent. retained in the fattening increase in live-weight. The cereal grains, on the other hand, which are much less rich in nitrogen, contribute a much larger proportion of their total amount to the increase; indeed, generally about 10 per cent. of it. The gramineous straws contribute a higher proportion still; whilst the roots lose by feeding on an average only about 5 or 6 per cent. of their nitrogen.

It is thus seen that, when fattening increase only is produced, the proportion of the nitrogen of the food which is retained by the animal, and so lost to the manure, is very small in the case of the richer foods, but more in that of the poorer ones; but even with them it seldom exceeds 10 per cent., excepting with the straws. It may be assumed, however, that when the foods are consumed by store animals, about twice as much of the nitrogen of the food is retained by the animal, and so lost to the

manure. And when, as is more and more the case with early maturity, the increase comprises a larger proportion of growth than in mere fattening, the amount of the nitrogen of the food which will be lost to the manure will be between that given in the Table and twice as much.

The third division of the Table relates to the phosphoric acid, and there are given for each food, as in the case of the nitrogen, the amounts of it per cent. and per ton, of the foods; the amount estimated to be retained in the increase; the amount remaining for manure, and the money-value of this at 3*d.* per lb.

It will be seen that there is only about two-thirds as much phosphoric acid as of nitrogen retained in a given weight of fattening increase; but owing to the very generally less, and sometimes much less, amount of it in the foods, a greater proportion of that consumed is retained in the animal, and a less proportion remains for manure. It should be added that, in the case of store and still growing animals, the amount of phosphoric acid retained in a given weight of increase will be very much greater than in mere fattening; indeed in mere store increase it may, as in the case of the nitrogen, be nearly twice as great as in mere fattening.

Of potash, the Table shows that a given weight of fattening increase retains only about one-eighth as much as it does of phosphoric acid; and the percentage of the whole in the food which is lost to the manure is generally very small. In its case, as in that of the nitrogen and phosphoric acid, the amount retained in mere store increase will be nearly twice as much as in mere fattening increase, but the total quantity retained is still very small. The potash remaining for manure is valued at 2½*d.* per lb.

The last column of Table II. shows the total manure-value of a ton of each of the foods after consumption, reckoning the nitrogen, the phosphoric acid, and the potash, at the prices above named, which are those at which they can, at the present time, be purchased in artificial manures. In our formerly-published estimates we valued the nitrogen and phosphoric acid at the prices at which they could then be purchased in Peruvian guano. In those estimates ammonia was taken at 8*d.* per lb., but now it is reckoned at only 6*d.*; phosphoric acid was taken at about 2¼*d.*, but now at 3*d.* per lb. (as in "precipitated phosphate"); and potash was then valued at 2*d.* per lb., but now at 2½*d.*

Notwithstanding the somewhat higher value now given to phosphoric acid and potash, and the less amount of the nitrogen of the food now reckoned to be lost by the feeding, the reduction in the price of ammonia by one-fourth, brings all the estimates of total, or original manure-value lower now than formerly.

Thus, the total manure-value of a ton of linseed-cake consumed, which was previously reckoned at 4*l.* 12*s.* 6*d.*, is now taken at 3*l.* 18*s.* 6*d.*; that of a ton of maize is reduced from 1*l.* 11*s.* to 1*l.* 5*s.* 1*d.*; and that of other foods in varying proportions, depending partly on the alteration (if any) in the adopted average composition of the foods, but mainly on the reduction in the money-value assigned to ammonia.

III. Unexhausted Manure-value of Cattle Foods.

So much for the method, and the results, of the estimation of the *total* or *original manure-value* of the different foods, deducting merely the nitrogen, the phosphoric acid, and the potash, estimated to be retained by the animal consuming them, and reckoning the remainder at the prices at which they can be purchased in artificial manures. We have now to attempt the still more complicated and difficult task of endeavouring to estimate the *unexhausted manure-value* of the different foods, or what may be called their *compensation-value*, after they have been used for a series of years by the outgoing tenant, and he has realised a certain portion of the manure-value in his increased crops.

As already said, we have in the case of a number of the foods endeavoured to estimate the probable amounts of increase that the tenant would obtain in his barley and wheat crops, supposing that the food were used at the rate of one ton per acre in eight years, or one ton over 8 acres each year; and then, after making allowance for loss, we have estimated the value of the unexhausted residue at a declining rate from the last to the eighth year. These results gave a basis for consideration, and, having studied them, and settled what seemed to be a suitable allowance, we have fixed upon a scale of reduction, starting from the *original manure-value* as estimated in Table II.

The rule so determined upon is—to deduct one-half of the original manure-value of the food used the last year, and one-third from year to year, each year to the eighth, in the case of all the more concentrated foods, and the roots, in fact of all the foods in the list excepting the hays and the straws; and for these, which contain larger amounts of indigestible matter, and the constituents of which will be more slowly available to crops, two-thirds of the original manure-value is deducted for the last year, and only one-fifth from year to year to the eighth year.

The results of the estimates of *compensation-value* so made are given in Table III. (p. 19). The first column shows the *total* or *original manure-value* of each food. The second column shows the allowance for the last year, and the succeeding seven columns that for each succeeding year to the eighth. The last

TABLE III.—PLAN and RESULTS of ESTIMATIONS of the COMPENSATION-VALUE of UNEXHAUSTED MANURE, starting from the ORIGINAL MANURE-VALUE, that is the VALUE, deducting the constituents of increase in FATTENING LIVE-WEIGHT only.

Foods.	Original Manure-value, deducting Increase in Live-weight only.	Compensation-value of Unexhausted Manure.							
		Last Year.	Second Year.	Third Year.	Fourth Year.	Fifth Year.	Sixth Year.	Seventh Year.	Eighth Year.	Total.
DEDUCT ⅛ of ORIGINAL MANURE-VALUE the LAST YEAR, and ⅛ from YEAR to YEAR.										
One Ton.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	£ s. d.
1. Linseed	2 19 5	1 9 9	0 19 10	0 13 2	8 10	5 10	3 11	2 7	1 9	4 5 8
2. Linseed-cake	3 18 6	1 19 3	1 6 2	0 17 6	11 8	7 9	5 2	3 5	2 4	5 13 3
3. Decorticated cotton-cake ..	5 13 0	2 16 6	1 17 8	1 5 1	16 9	11 2	7 5	4 11	3 4	8 2 10
4. Palm-nut cake	1 19 10	0 19 11	0 13 3	0 8 10	5 11	3 11	2 8	1 9	1 2	2 17 5
5. Undecorticated cotton-cake	3 8 8	1 14 4	1 2 11	0 15 3	10 2	6 10	4 6	3 0	2 0	4 19 0
6. Cocoa-nut cake	3 0 7	1 10 3	1 0 2	0 13 5	9 0	6 0	4 0	2 8	1 9	4 7 3
7. Rape-cake ..	4 5 4	2 2 8	1 8 6	0 19 0	12 8	8 5	5 7	3 9	2 6	6 3 1
8. Peas	2 15 0	1 7 6	0 18 4	0 12 3	8 2	5 5	3 7	2 5	1 7	3 19 3
9. Beans	3 3 5	1 11 9	1 1 2	0 14 1	9 5	6 3	4 2	2 9	1 10	4 11 5
10. Lentils	3 1 4	1 10 8	1 0 5	0 13 8	9 1	6 1	4 1	2 8	1 9	4 8 5
11. Tares (seed)..	3 2 1	1 11 1	1 0 8	0 13 9	9 2	6 1	4 1	2 9	1 10	4 9 5
12. Indian corn ..	1 5 1	0 12 6	0 8 4	0 5 7	3 8	2 6	1 8	1 1	0 9	1 16 1
13. Wheat	1 8 7	0 14 3	0 9 6	0 6 4	4 3	2 10	1 11	1 3	0 10	2 1 2
14. Malt	1 6 8	0 13 4	0 8 11	0 5 11	4 0	2 8	1 9	1 2	0 9	1 18 6
15. Barley	1 6 1	0 13 1	0 8 8	0 5 9	3 10	2 7	1 9	1 2	0 9	1 17 7
16. Oats	1 9 10	0 14 11	0 9 11	0 6 8	4 5	2 11	2 0	1 4	0 11	2 3 1
17. Rice meal ..	(1 7 10)	(0 13 11)	(0 9 3)	(0 6 2)	(4 1)	(2 9)	(1 10)	(1 3)	(0 10)	(2 0 1)
18. Locust beans	..	..	..	..	..	..	..	..	..	..
19. Malt coombs	3 10 9	1 15 4	1 3 7	0 15 9	10 6	7 0	4 8	3 1	2 1	5 2 0
20. Fine pollard ..	2 13 4	1 6 8	0 17 10	0 11 10	7 11	5 3	3 6	2 4	1 7	3 16 11
21. Coarse pollard	2 17 9	1 8 10	0 19 3	0 12 10	8 7	5 8	3 10	2 7	1 8	4 3 3
22. Bran	2 18 5	1 9 2	0 19 6	0 13 0	8 8	5 9	3 10	2 7	1 8	4 4 2
DEDUCT ⅛ of ORIGINAL MANURE-VALUE the LAST YEAR, and ⅛ from YEAR to YEAR.										
One Ton.										
23. Clover hay ..	2 1 3	0 13 9	0 11 0	0 8 9	7 0	5 7	4 6	3 7	2 11	2 17 1
24. Meadow hay ..	1 8 7	0 9 6	0 7 7	0 6 1	4 11	3 11	3 2	2 6	2 0	1 19 8
25. Pea straw ..	0 18 10	0 6 3	0 5 0	0 4 0	3 3	2 7	2 1	1 8	1 4	1 6 2
26. Oat straw ..	0 11 7	0 3 10	0 3 1	0 2 6	2 0	1 7	1 3	1 0	0 10	0 16 1
27. Wheat straw	0 10 1	0 3 4	0 2 8	0 2 2	1 9	1 5	1 1	0 11	0 8	0 14 0
28. Barley straw	0 10 1	0 3 4	0 2 8	0 2 2	1 9	1 5	1 1	0 11	0 8	0 14 0
29. Bean straw ..	0 17 7	0 5 10	0 4 8	0 3 9	3 0	2 5	1 11	1 6	1 3	1 4 4
DEDUCT ⅛ of ORIGINAL MANURE-VALUE the LAST YEAR, and ⅛ from YEAR to YEAR.										
Ten Tons.										
30. Potatoes ..	3 4 2	1 12 1	1 1 5	0 14 3	9 6	6 4	4 3	2 10	1 11	4 12 7
31. Carrots	2 2 6	1 1 3	0 14 2	0 9 5	6 4	4 2	2 10	1 10	1 3	3 1 3
32. Parsnips ..	2 14 2	1 7 1	0 18 1	0 12 1	8 0	5 4	3 7	2 4	1 7	3 18 1
33. Mangel wurzels	2 10 0	1 5 0	0 16 8	0 11 1	7 5	4 11	3 4	2 2	1 6	3 12 1
34. Swedish turnips	2 5 10	1 2 11	0 15 3	0 10 2	6 10	4 6	3 0	2 0	1 4	3 6 0
35. Yellow turnips	(1 19 2)	(0 19 7)	(0 13 1)	(0 8 9)	(5 10)	(3 11)	(2 7)	(1 9)	(1 2)	(2 16 8)
36. White turnips	2 0 0	1 0 0	0 13 4	0 8 11	5 11	3 11	2 8	1 9	1 2	2 17 8

column gives the *total compensation-value* for the eight years consumption.

It may seem at first sight that a deduction of 50 per cent. from the original manure-value of the food used in the last year is large; but we have not only to make allowance for all losses to which the manure may be subject, which may be considerable, especially if much of the food is consumed in the yards; but it is also to be borne in mind that the money paid for compensation will not yield its full return for a long time. Only half the original manure-value would therefore be allowed if the food were only used one year; and all scales of allowance arranged by Farmers' Clubs assume the consumption for more than one year. If, however, the food is used for eight years, or more, it will be seen that the total allowance considerably exceeds the original manure-value of one year's consumption; the allowance made for the accumulation bringing it up to from one-and-a-third to one-and-a-half as much as the original manure-value.

In order to test the applicability of the scale of compensation proposed, let us take a very simple and ordinary case, and see what would be the allowance allotted to the outgoing tenant according to the estimate given in the Table. Let us suppose the case of a Norfolk or Lincolnshire farm under the ordinary four-course rotation, with meat and grain only sold, the roots fed partly on the land and partly in the yards. Assume, further, that the land is thoroughly clean, and that the farm is in every respect in good order when given up. It is pretty certain, indeed, that every claim for compensation will have to be settled on its own merits; that the character of the soil, the cropping, the state of the land as to cleanliness, and many other points, will be taken into consideration, both for and against any claim.

As already intimated, the essential basis of the system of estimate and valuation of the unexhausted residue adopted, is the assumption of gradual accumulation within the soil, and of slow recovery from it. Suppose then that linseed-cake had been used annually for eight years, at the average rate of one ton over eight acres each year, or of one ton per acre in eight years. Each acre would thus, on the average receive, either in farm-yard-manure, or directly by the feeding with roots or clover on the land, the manure from the consumption of one ton of linseed-cake in eight years, or at the average rate of one-eighth of a ton, or 2½ cwts., per acre, per annum.

The first column of Table III. (p. 19) shows that the *original manure-value* of one ton of linseed-cake consumed, that is, the value deducting only the constituents stored up in the animal, is estimated to be 3*l.* 18*s.* 6*d.* The subsequent columns of the

same Table show the estimated *compensation-value* of the *unexhausted residue* from one ton consumed (that is, after the tenant has realised the benefit of the increase of his crops), to be, if used each year for eight years, as given in the first column of the following Table; the second column showing the amount per acre per annum:—

	Compensation Allowance for One Ton of Linseed-cake consumed.	
	Per Annum, Eight Years.	Per Acre, in Eight Years.
	£ s. d.	£ s. d.
Last year	1 19 3	0 4 11
2nd „	1 6 2	0 3 3
3rd „	0 17 6	0 2 2
4th „	0 11 8	0 1 6
5th „	0 7 9	0 1 0
6th „	0 5 2	0 0 8
7th „	0 3 5	0 0 5
8th „	0 2 4	0 0 3
Total	5 13 3	0 14 2

Thus, according to the first column of the Table, the value of the unexhausted manure-residue from the consumption of one ton of linseed-cake annually for eight years would be 5*l.* 13*s.* 3*d.*, or nearly 45 per cent. more than the original manure-value of one year's consumption. Or, as the second column shows, the allowance would be at the rate of 14*s.* 2*d.* per acre over the whole farm.

Whether such an allowance would be too much or too little under the circumstances supposed, is a question for consideration. The conditions supposed are—a light-land farm, upon which the manure from purchased food is an essential element of profitable cultivation; that meat and grain alone are sold; and that the farm is given up in a satisfactory state in every respect. Also that each acre received, on the average, during the last eight years, the manure derived from the consumption of one ton of linseed-cake. The question between the two parties concerned is, whether the outgoing tenant would receive sufficient remuneration for his unexhausted manure? and, on the other hand, whether the landowner, or the incoming tenant, would pay more than will be recovered in increase of crops? An allowance of 14*s.* 2*d.* per acre on a farm of 400 acres, would amount to 283*l.* 6*s.* 8*d.*, which is a large sum to pay; and it is certain that the recovery of the amount will only be gradual. It is well known that both time and money are required to get land into condition, and here is land already in condition.

Let us consider the effect of such a valuation of unexhausted manure from two opposite points of view. The outgoing tenant may consider that he is entitled to a larger sum, and he prefers to claim compensation under the Act. The outgoing tenant of the future will, however, have another alternative. He can reduce the stock of fertility by the consumption of foods which have high feeding- but low manure-value, and which are lower in price than the foods which possess both high feeding- and high manure-value. The incoming tenant knows what he has to pay for, and has only himself to blame if he pays too much. But behind the incoming tenant is the landowner, who must himself pay the claim of the outgoing tenant if he can find no one else to do so. It is, therefore, a matter of importance to the landlord that the compensation should be fixed on a basis sufficiently reasonable to render it not worth his while to carry the case to arbitration, or into a court of law.

In 1876, Mr. Thomas Huskinson, who was at that time President of the Institute of Surveyors, gave evidence before the Chemical Committee of the Royal Agricultural Society in reference to the Lincolnshire custom. He said that compensation was the universal custom so far as cakes were concerned, but not in the case of any other foods. For cakes, one-half the cost of the last year's consumption was allowed; but this was not to be more than the average of the two preceding years. At that date the price of linseed-cake was higher than at present, and very much higher than was that of decorticated cotton-cake, which was only used in comparatively small quantities, nor was its higher manure-value generally recognised. It may be observed that the above allowance of 5*l.* 13*s.* 3*d.*, founded, not on cost, but on original and unexhausted manure-value, would considerably exceed half the cost of one year's consumption at the present price of linseed-cake.

It must be evident that the custom of giving compensation upon cakes alone, as in Lincolnshire and some other counties, has acted as a bounty in favour of such foods, and has so artificially enhanced their relative price. The Act of 1883, however, gives compensation for unexhausted manure-value, whenever it can be proved to exist, by the use of whatever food, or manure, it may have been accumulated in the soil. It is very desirable, therefore, to endeavour to make, and to publish, for the information and the consideration of those whose business it is to settle claims for compensation, the best estimates which the knowledge of the time permits—of the average composition, not only of cakes, but of all other foods likely to be used, of their total or original manure-value after consumption, and of their unexhausted manure-value after they have yielded increase of the crops grown.

It will be obvious that, if it be once admitted, that the manure-value of foods depends on their composition, and on the date of their consumption, it is very important that farmers should be at liberty to use those foods which are at the time the cheapest, or otherwise the most advantageous. It is true that, hitherto, he could do so, but not without running the risk of losing his claim for compensation for unexhausted fertility; or, at any rate, he would not benefit from those arrangements for compensation which have been made between owners and occupiers of land to avoid litigation. Such arrangements are most laudable; but they have been confined in their application to a few favourite articles, which have thereby been enhanced in price beyond their natural commercial value. It is in the hope that the extension of such arrangements to foods generally will be facilitated, that we have been encouraged to draw up and to publish the Table of allowances now under consideration.

As before referred to, we have, in the construction of the Table (III., p. 19) in all cases adopted one uniform rate of deduction from year to year, excepting in those of the hays and the straws, as already explained, and as shown in the Table. We do not, however, at all assume that there is no difference in the activity of the manure from the different foods thus classed together, or that their unexhausted residue will be available at exactly the same rate. Then, again, it is obvious that to assume the consumption, and the manure-value, to be the same on each cre, and in each year, is not strictly in accordance with the facts, as one year the food will produce animal increase, and another year increase in crops, and so on. But to have attempted to fix a different scale for each food, and for each year, according to such circumstances, would have been to assume a knowledge which we do not possess. We have thought it better, therefore, to submit the Table for the consideration of those interested, as the best approximation to the truth that we are at present able to provide.

Although it is to be borne in mind that the whole of the estimates are founded on the assumption that fattening increase only is produced, yet we have indicated the direction, and indeed to a considerable extent the degree, in which the figures should be modified when store animals are reared or fed. It should be added that, in the case of the foods being used for the production of milk, an entirely different scale of original and unexhausted manure-value would have to be arranged, as milk removes so very much more of the manure-constituents of the food than increase in live-weight of any kind.

In conclusion, although we were only requested to revise the Table of total, or original manure-values of food-stuffs, chiefly

as affected by the change in the price of ammonia, we have thought it desirable to carry the subject further, and to endeavour to put forward a scheme for the valuation of *unexhausted manures* also. The results will doubtless require revision from time to time, as the value of manure-constituents in the market changes, and perhaps also in other ways, as knowledge advances, and experience is gained. But the passing of the Act of 1883, and the problems and the discussions to which it must necessarily give rise, seemed to render such an attempt very opportune at the present time. It is to be understood, however, that in the use of the Table, the special circumstances of each case must be taken into account, and the actual figures adopted, or modification made, accordingly. Independently of such direct application of the results, it will be a point of importance gained, if valuations come to be made on the basis of manure-value, and not of cost; and perhaps one of still greater importance, if the scale we have submitted should lead to the general recognition of the fact that unexhausted manure-value should be subject to compensation, from whatever food it may have been derived; thus enabling the farmer to use any food that may be the most advantageous at the time, without fear of losing his claim to compensation under amicable arrangements. At any rate, as we have given the data on which our estimates are founded, and explained the method by which they have been obtained, those interested in this most difficult subject have the means of forming their own conclusions on the results arrived at.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,

ON THE

GROWTH OF BARLEY,

FOR MORE THAN THIRTY YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JUNE 29, 1886,

AT THE

ROYAL AGRICULTURAL COLLEGE,

CIRENCESTER,

BY

J. H. GILBERT, M.A., LL.D., F.R.S.,

SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD,

AND

HONORARY PROFESSOR OF THE COLLEGE.

FROM THE "AGRICULTURAL STUDENTS' GAZETTE,"
NEW SERIES—VOL. III. PART I.

RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF BARLEY,

FOR MORE THAN THIRTY YEARS IN SUCCESSION ON THE SAME LAND.

CONTENTS.

	PAGE
INTRODUCTION	1
THE ROTHAMSTED FIELD EXPERIMENTS ON BARLEY	3
RESULTS WITHOUT MANURE, AND WITH FARMYARD MANURE...	4
RESULTS WITHOUT MANURE, AND WITH ARTIFICIAL MANURES	7
INFLUENCE OF SEASON ON THE AMOUNTS OF PRODUCE	14
INFLUENCE OF EXHAUSTION, MANURES, AND VARIATIONS OF SEASON, ON THE COMPOSITION OF THE BARLEY CROP	17
ON WHAT DOES STRENGTH OF STRAW DEPEND?	25
OUR AREA UNDER THE CROP AND THE AMOUNT OF OUR IMPORTS	26
CONCLUSION	29

Introduction.

In my lecture last year I gave an account of the experiments at Rothamsted on the growth of wheat for more than forty years in succession on the same land, without manure, with farm-yard manure, and with a great variety of artificial manures.

Attention was directed to the fluctuations in the amounts of produce from year to year, and to the average yield per acre over the earlier, the later, and the total period of the experiments, under each of the very varying conditions as to manuring.

The results of collateral investigations were also adduced.

For example, the increased assimilation and yield of carbon per acre in the crop, for a given amount of nitrogen supplied in manure, and the connection between carbon-assimilation, nitrogen-accumulation, and chlorophyll-formation, were shown. The proportion of the nitrogen supplied in the manure, which was respectively recovered in the increase of the crop, lost by drainage, or accumulated as crop-residue in the surface soil, was pointed out. The influence of exhaustion, or of full supply of the mineral constituents, on the mineral composition of the crop was shown; the general result being that whilst the amounts taken up by the entire plant, as represented by the quantities contained in the total produce, corn and straw together, varied considerably according to the supply within the soil, the amounts accumulated in the final and definite product, the grain, were under otherwise equal conditions nearly identical.

The influence of season was illustrated by the results obtained in the best and the worst seasons of the forty years. The general accordance of the Rothamsted results with those obtained on other soils and in other localities was next pointed out, and it was shown that at Woburn,

as at Rothamsted, when nitrogen was supplied as ammonium-salts, or as nitrate of soda, for wheat or barley, comparatively little of that which was not recovered in the immediate increase of crop, was recovered in the succeeding crops.

Leaving the experimental results, attention was directed to the average yield of wheat per acre in the United Kingdom over a period of 32 years. It was shown how greatly the area under the crop had diminished during that period, but that our yield per acre was greater than that of any other wheat growing country, and very much greater than that of the chief exporting countries, such as the United States, Canada, or India; and very much greater also than in most of the European countries where peasant proprietors or small holdings prevail.

The consideration of these facts naturally led to a consideration of the characteristic differences, in some important respects, of old arable soils, of pasture soils, and of prairie and other virgin soils. It was shown that a fertile soil was one which had accumulated within it, the residue of ages of previous vegetation, and that it becomes infertile as that residue is exhausted. Finally, it was concluded that it was extent of area, and cheap fertility, not good cultivation, against which the British wheat grower had to contend.

In the present lecture I propose to bring before you the results obtained at Rothamsted, on the growth of barley, not for more than forty years, but for thirty-four years in succession on the same land. The collateral investigations in connection with barley are not so numerous, or of such general interest or importance, as those to which attention was called in the case of wheat, but I shall be able to illustrate the influence of exhaustion, manures, and variations of season, on the amounts of produce, and to some extent on the composition of the crop. In conclusion, I shall adduce some statistics relating to our area under the crop, to the amount of our imports, and to the sources whence they are derived.

Barley, like wheat, is a member of the great gramineous family of plants, to which we owe so many, and such important economic products. In our own country and climate, barley comes second to wheat in importance among the cereal crops we cultivate; though, in the north, oats gain in relative consideration. The average area under *barley* in the United Kingdom is, however, only about four-fifths as great as that under wheat; and we shall see that it, like the area under wheat, has of late years diminished.

In countries with warmer and longer summers another gramineous grain crop, Indian corn, or maize, comes into prominence; and in warmer countries still grows the sugar cane. Indeed it is to this family that we owe our chief *starch-* and *sugar-* yielding crops; and it is somewhat remarkable that the plants which, at any rate in temperate climates, come next in importance as starch- and sugar- yielding crops, should belong to such widely different orders as the *Solaneæ* giving us the potato, and the *Chenopodiaceæ* giving the sugar beet, mangel wurzel, &c., whilst the organs, or parts of the plants, which yield the

products are also widely different. In each case, however, it is the store of reserve material which the plant has laid up for reproduction which we turn to economic account.

But not only does the gramineous family provide us with our chief starch and sugar yielding crops, but it contributes a large proportion of the natural and cultivated herbage, upon which animals of use to man are fed over very large portions of the globe.

Although *wheat* and *barley* are thus closely allied botanically, and they have, moreover, in some respects very similar requirements as cultivated crops, yet it will be found that there are distinctions as well as similarities which it is important to recognise.

To refer to one or two points of distinction which obviously must have an influence on the results obtained in experiments on the growth of the two crops, and which must be borne in mind in their interpretation, it may be mentioned that, in our own country and climate at any rate, wheat is almost invariably sown in the autumn, whilst barley is as generally not sown until the spring.

Thus, wheat has four or five months for root-development, and for gaining possession of range of soil, before barley is sown. Under these circumstances, too, the conditions of soil most suitable to the two crops are very different. For wheat a comparatively heavy soil is adapted, and a fine tilth, encouraging superficial root-development, is not desirable. For barley, on the other hand, a comparatively light soil is more appropriate, and a fine tilth is of great importance. In other words, with the characteristic habit of growth of the plant, and the short period at its command for root-development, a very permeable surface-soil is a desideratum.

In these facts we have the indication that wheat acquires a much greater root-range, and consequently a command of the resources of a more extended range of both soil and subsoil; whilst barley must, in a greater degree, be dependent on the supplies within the surface-soil, and so be the more susceptible to the influence of the exhaustion, or the supplies, within the surface-soil.

Bearing these various points in mind, we may now turn to the results of long-continued field-experiments on the growth of barley, by different manures, and in different seasons, and to the evidence of collateral Laboratory investigations as to its composition.

The Rothamsted Field Experiments on Barley.

The Rothamsted Field Experiments on Barley were commenced in 1852, that is eight years later than those on wheat, but at the same time as that at which the arrangements of the plots in the Experimental Wheat Field devoted to chemical or artificial manures became more systematic and permanent.

The barley crop of last year, 1885, was the thirty-fourth in succession on the same land, and the thirty-fifth crop is now growing. There are nearly thirty experimental plots. Two have been unmanured from the commencement. One has received farm-yard manure every year, or rather one-half of it has, for after twenty years the plot was

divided, one half being still annually manured as before, and the other half then left unmanured, to test the effects of the unexhausted residue of the twenty years' previous applications of farm-yard manure. The other plots have annually received artificial manures, for the most part the same year after year, from the commencement; but there have been a few changes, some of which will be explained as we proceed.

Results without Manure, and with Farmyard Manure.

The results to which I shall first direct your attention are those obtained *without manure*, and with *farmyard manure*. Table I. (p. 5) gives the produce of grain per acre in each year, and also the average produce over selected series of years, and over the whole period of 32 years, to 1883 inclusive.

The first column of the Table gives the produce without manure. Columns 2 and 3 give the produce by farmyard manure for the first twenty years (1852-1871) over the whole plot, and for the next twelve years (1872-1883). Column 2 gives the produce on the half of the plot on which the application was still continued, and column 3 that on the other half where the application was discontinued after the first twenty years, showing therefore the effects of the residue of the previous applications. Column 4 shows, for the last twelve years, the excess of produce on the plot where the application was continued over that where it was discontinued; and the last two columns show the increase over the unmanured produce, first by farmyard manure continuously applied, and secondly by the residue of the applications of the first twenty years.

First referring to the produce *without manure*, it is seen that in two years, the third and fourth, the yield was over thirty bushels per acre; in six years during the first thirteen, the produce was between twenty and thirty bushels, but it never afterwards reached twenty bushels, and in twenty-four out of the thirty-two years the yield was less than twenty bushels; in two of these it amounted to only ten, and in one (1879), to only 6¼ bushels.

There was thus a very great variation in the amount of produce without manure from year to year according to season. A glance at the figures, and especially at the average produce over successive series of years, as given at the foot of the Table, shows, however, that independently of these fluctuations due to season, there was a progressive decline due to exhaustion; though the last four years gave a higher average than any other four in the last sixteen years.

It may be observed that without manure there is a decline in the produce of barley grain of 31·4 per cent. over the second sixteen years compared with the first sixteen; and that this rate of decline is considerably greater than was found in the case of wheat. This result is doubtless due to the shorter period of growth, and the greater dependence on the surface soil, in the case of the barley; and hence exhaustion is the sooner manifested.

We now turn to the produce by *farmyard manure*. As without manure, there is very great fluctuation from year to year according to

TABLE I

Barley 32 years in succession on the same land, Hoosfield, Rothamsted.

Produce—Without Manure, and with Farm-yard Manure.

DRESSED GRAIN PER ACRE, BUSHELS.

	Un-manured every year	FARM-YARD MANURE				
		Every year 1852-83	20 years, 1852-71 Un-manured 1872-83	Continuous + or — Un-manured after 20 years	+ Unmanured	
					Manured every year	Manured 20 years, Unmanured afterwards
	Plot 1-0	Plot 7-2	Plot 7-1		Plot 7-2	Plot 7-1
1852	27½	38			+ 5½	
1853	25½	36⅛			+ 10⅛	
1854	35	56⅜			+ 21⅜	
1855	31	50⅛			+ 19⅛	
1856	13⅞	33½			+ 18½	
1857	26⅜	51½			+ 25⅛	
1858	21½	55			+ 33½	
1859	13⅜	40			+ 26⅝	
1860	13½	41⅜			+ 28⅜	
1861	16⅜	54⅜			+ 38⅛	
1862	16⅛	49½			+ 33½	
1863	22½	59½			+ 36⅜	
1864	24	62			+ 38	
1865	18	52½			+ 34½	
1866	15⅞	53⅛			+ 37½	
1867	17⅜	45⅜			+ 28⅛	
1868	15⅛	43⅜			+ 28	
1869	15⅜	46⅝			+ 31½	
1870	13⅜	47⅜			+ 34	
1871	16½	54½			+ 37½	
1872	10½	38⅞	38½	+ 0⅜	+ 28⅜	+ 28
1873	14	54½	47½	+ 6½	+ 40½	+ 33½
1874	17⅜	64½	46⅜	+ 18	+ 46⅞	+ 28⅞
1875	19½	45¼	32½	+ 12¾	+ 32½	+ 20
1876	19⅜	45	31	+ 14	+ 32½	+ 18½
1877	17⅜	52	36	+ 16	+ 34½	+ 18½
1878	10	46½	21½	+ 24⅜	+ 36¼	+ 11¼
1879	6½	36⅜	16⅜	+ 20	+ 30⅜	+ 10⅜
1880	18½	65½	41⅜	+ 23⅜	+ 46⅜	+ 22⅜
1881	17½	53⅜	29½	+ 24	+ 35½	+ 11½
1882	18⅜	60⅜	35	+ 25⅜	+ 42⅜	+ 16⅜
1883	16½	58⅜	35½	+ 23	+ 42¼	+ 19½
AVERAGES						
4 yrs. 1852-55	29¾	43½			+ 14⅛	
,, 1856-59	18⅜	44⅜			+ 26	
,, 1860-63	17½	51⅜			+ 34⅛	
,, 1864-67	18½	53⅜			+ 34⅜	
,, 1868-71	15½	48			+ 32½	
,, 1872-75	13⅜	50½	41½	+ 9⅛	+ 37⅛	+ 27⅜
,, 1876-79	11½	45	26⅜	+ 18⅜	+ 33¼	+ 14½
,, 1880-83	17⅜	59½	35½	+ 24	+ 41¼	+ 17⅜
10 yrs. 1852-61	22⅜	45			+ 22⅜	
10 ,, 1862-71	17½	51½			+ 34	
20 yrs. 1852-71	19½	48½			+ 28⅜	
12 ,, 1872-83	14⅜	51½	34⅜	+ 17⅜	+ 37⅜	+ 20
32 yrs. 1852-83	17⅜	49½	43		+ 31⅜	+ 25½
Last 12 yrs. P.C. +or—first 20 yrs.	— 27·7	+ 7·3	— 28·6			

season; but instead of a gradual decline there is an obvious increase in the yield over the later years, due to the accumulation of the manure. There is, in fact, instead of a decline of 27·7 per cent., an increase of 7·3 per cent. over the last twelve years compared with the first twenty; although the second period included a number of the worst seasons of the whole series of years.

In four of the thirty-two years the farmyard manure gave more than 60 bushels of barley per acre, in thirteen years between 50 and 60 bushels, in ten between 40 and 50 bushels, in five between 30 and 40 bushels, and in no case below 30 bushels. The average yield was, over the first twenty years 48¼ bushels, over the last twelve years 51¾ bushels, and over the thirty-two years 49½ bushels, against 17⅞ bushels without manure.

So much for the produce of barley obtained by the unusual application of fourteen tons of farmyard manure per acre per annum, for thirty-two years in succession. It is estimated that the manure supplied about 200 lbs. of nitrogen per acre per annum, or over twenty years 4,000 lbs. of nitrogen. It was further estimated that at the end of twenty years, not more than fourteen or fifteen per cent. of this large amount of nitrogen had been removed in the increase of crop. There must, therefore, have been a great accumulation of nitrogen, and other constituents, within the soil; and analysis proved that this was the case. Indeed, it was calculated that, if there were no loss of nitrogen, by drainage, by evolution of free nitrogen, or otherwise, and if the accumulated residue were as available as that which had already been effective, the produce should be maintained at the level of that of the first twenty years for not far from 150 years more.

Let us see what was the result of stopping the application of manure on half the plot after the first twenty years? This is shown in the lower division of the table. The second column shows the produce of the last twelve years, where the application was continued; the third column where it was discontinued; the fourth the excess yielded by the continuous application over that by the residue from previous applications. Lastly, the fifth column shows the increase over the unmanured produce, by the continuous application, and the sixth that by the residue.

Comparing the second and third columns, it is seen that there is a general tendency to increase in yield where the application of the farmyard manure was continued, and to decrease where it was discontinued. This result is brought prominently to view in column 4, which shows that the difference between the amount of produce gradually increases until during the last four of the twelve years, the *manure-residue* plot shows an average of about twenty-four bushels per acre per annum less than where the application was continued.

The averages at the foot of the table show that over the first twenty years, with the continuous application the yield was 48¼ bushels, whilst over the succeeding twelve years, it was, where the application was continued 51¾ bushels, but where it was discontinued

only 34⅜ bushels; showing, therefore, an average annual deficiency under the influence of the residue only, of 17⅜ bushels, or of 33·6 per cent.

Taking as the standard of comparison the unmanured produce (which, however, itself gradually declined), the last two columns show that over the three four-yearly periods of the last twelve years, the increase of produce was with the continued application 37⅛, 33½, and 41¾ bushels, but with the residue only 27⅝, 14⅞, and 17⅝ bushels. Over the whole twelve years there was an average annual increase of 37⅜ bushels with the continued application, and of only 20 bushels with the residue.

It may be observed that over the whole period of thirty-two years, the total produce (grain and straw together) was without manure less than one ton per acre per annum, whilst with the farmyard manure it was 2¾ tons, and in some years it reached from 3½ to 3¾ tons.

To sum up in regard to the foregoing results—there was gradual exhaustion and reduction of produce without manure, and gradual accumulation and increase of produce with the annual application of farmyard manure. But when the application was stopped, although the effect of the residue from the previous applications was very marked, it somewhat rapidly diminished, notwithstanding that calculation showed an enormous accumulation of nitrogen as well as other constituents.

Indeed, determinations of nitrogen in the surface-soil, after the twenty years application of farmyard manure, showed it to be nearly twice as high as on the unmanured plot.

How then is the reduction of produce to be accounted for? The nitrogen of farmyard manure must obviously exist in very different conditions. That due to the urine of the animals will be the most rapidly available, that in the finely comminuted matter in the fæces will be much more slowly available, and that in the litter still more slowly available. Hence the small proportion that is at once effective, and the very large amount that accumulates within the soil in a very slowly available condition.

But the evidence at command leads to the conclusion that neither in the wheat field, nor in the barley field, does the accumulation within the soil account for the whole of the nitrogen supplied which is not recovered in the immediate increase of crop. Some is doubtless lost as nitrates by drainage, and some probably by evolution as free nitrogen. The fact of such losses is of considerable interest; but it is some consolation to believe that the loss will be proportionally very much less in ordinary farm practice, where the amounts of farmyard manure applied are much less, and where various crops, with different root-ranges, and different periods of accumulation, are grown.

Results without Manure, and with Artificial Manures.

We have next to consider—what is the character of the exhaustion induced by the growth of the crop without manure? and to what constituent, or constituents, of farmyard manure, its effects are mainly to be attributed? These points will be illustrated by the results given in Tables II. and III. (p.p. 8 and 9), which show the effects of various

TABLE II

Barley 34 years in succession on the same land, Hoosfield, Rothamsted.

Results showing the effects of exhaustion and Manures.

Dressed Grain per Acre, Bushels. Manure and produce per Acre per annum.

	SERIES 1				SERIES 2 200 lbs. Ammonium-Salts = 43 lbs. N.			
	Unmanured	Superphosphate of Lime	Potassium Sodium, and Magnesium Sulphates	Mixed Mineral Manure (2 & 3 mixed)	Alone	And Superphosphate of Lime	And Potassium Sodium and Magnesium Sulphates	And Mixed Mineral Manure (2 and 3 mixed)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
1852	27½	28⅝	26½	32⅝	36¾	38⅝	36	40⅜
1853	25¾	33½	27⅝	35⅝	38⅝	40⅛	36½	38¼
1854	35	40⅝	36¼	42	47¾	60¼	50	60⅛
1855	31	36½	34¼	37⅛	44½	47½	44½	48⅝
1856	13⅞	17⅜	16⅝	19⅜	25	29½	28⅜	31⅜
1857	20⅛	33¼	22	39½	38¼	56½	42⅜	57⅜
1858	21⅛	29¼	24½	30¼	31½	51⅜	34½	51⅛
1859	13⅜	19⅜	15⅞	19¾	15⅜	34½	16⅜	34⅜
1860	12½	15½	15½	18½	26⅜	43⅜	28	42½
1861	16¼	25	16¾	29⅜	30½	55	32⅜	54⅜
1862	16¾	21¾	19¼	25⅜	31⅜	49⅜	35½	47⅜
1863	22⅜	32⅜	27⅜	33	42⅜	61⅛	48⅜	55⅜
1864	24	30½	29⅛	33½	36¾	58½	43¾	55⅛
1865	18	22¼	22	24⅜	29¼	48⅜	33¼	46⅜
1866	15⅞	22⅜	19⅛	24	27⅛	50½	27⅛	47
1867	17⅛	24⅜	17	30¾	30⅜	44	33	49¾
1868	15⅜	18½	14½	17⅜	20⅜	37⅜	25	34⅜
1869	15½	18½	18⅜	22½	27½	48	34⅜	49½
1870	13¾	18	16⅜	18¾	27⅜	41½	30¾	38
1871	16⅜	23⅛	19⅜	25	36⅜	45⅜	38⅜	46½
1872	10½	15⅜	10½	14½	26½	39⅜	30⅜	36¾
1873	14	19¾	14¾	20⅜	32⅜	50⅜	34¾	46¾
1874	17⅜	21½	17¾	19⅜	23½	42⅜	30⅜	45⅜
1875	19½	14⅜	14⅜	17⅜	27⅜	37	29½	35⅜
1876	19⅜	16½	19⅜	15⅜	21	33½	23⅜	35⅜
1877	17⅛	23⅜	20⅜	23⅜	35½	43⅜	41½	50⅜
1878	10	12⅜	7½	11⅜	14⅜	31⅜	20½	33⅜
1879	6½	7½	6⅜	7½	15½	27⅛	16⅜	27⅜
1880	18¾	28⅜	23¾	30½	33¾	55⅜	38½	54⅜
1881	17½	19½	17⅜	17⅜	33½	43⅜	37⅜	42⅜
1882	18⅜	21¾	19	23⅜	34¾	45½	39½	50⅜
1883	16½	22⅜	18⅜	24⅜	38⅜	49⅜	43⅜	52
1884	13¾	17⅜	13½	14⅜	26½	29	31	42½
1885	9½	12⅜	7⅜	12½	15⅜	29	15½	32
AVERAGES								
4 yrs. 1852-55	29¾	34⅜	31½	36⅞	42	46¾	41⅜	47
,, 1856-59	18⅜	24¾	22½	27⅜	27¾	42⅞	30½	43⅜
,, 1860-63	17½	23¾	20⅜	26½	32⅜	52⅜	36⅜	50½
,, 1864-67	18¾	25	21½	25⅜	31⅜	50⅜	34½	48½
,, 1868-71	15⅜	19½	17⅜	20⅞	28⅜	43¾	32½	42½
,, 1872-75	13⅜	17½	14½	17⅜	27½	42⅜	31⅜	41⅜
,, 1876-79	11½	15	11⅜	14½	21½	34⅜	25⅜	36½
,, 1880-83	17⅜	23	19⅜	23⅜	35½	48½	39⅜	49⅜
8 yrs. 1852-59	24½	29⅜	26⅜	32½	34⅞	44⅞	36½	45⅜
,, 1860-67	18	24⅜	20⅜	26	32½	51½	35½	49½
,, 1868-75	14½	18⅜	15½	19⅜	27⅜	42⅜	31⅜	41⅜
,, 1876-83	14⅜	19	15⅜	19½	28½	41½	32½	43½
16 yrs. 1852-67	21⅛	27⅛	23⅜	29⅛	33½	48	35⅜	47⅜
,, 1868-83	14⅜	18½	15½	19½	28⅜	42	32	42½
32 yrs. 1852-83	17⅞	23	19½	24½	30½	45	33⅞	44⅞
P.C. Reduction 2nd 16 yrs.	31·4	30·9	33·7	33·9	16·0	12·5	10·2	10·3

TABLE III

Barley 34 years in succession on the same land, Hoosfield, Rothamsted.

Results showing the effects of Exhaustion and Manures.

Dressed Grain per acre, Bushels. Manures and Produce per acre per annum.

	SERIES 3 275 lbs. Nitrate Soda = 43 lbs. N (1).				SERIES 4 1000 lbs. Rape Cake = 49 lbs. N (2)			
	Alone	Super-phosphate of Lime	Potassium Sodium and Magnesium Sulphates	Mixed Mineral Manure (2 and 3 mixed)	Alone	And Super-phosphate of Lime	And Potassium Sodium and Magnesium Sulphates	Mixed Mineral Manure (2 and 3 mixed)
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3	Plot 4
1852	44½	43⅝	41⅜	45⅜	39½	36½	33½	38
1853	40⅜	42½	41½	44⅞	39⅜	36⅞	35½	40⅜
1854	56⅜	63½	51⅜	62⅜	60½	60⅜	50⅜	60½
1855	48	50⅜	47½	49⅜	48⅜	53½	48⅜	51⅜
1856	36½	31⅛	25⅜	37⅜	36⅜	37⅛	32⅜	35⅜
1857	49⅜	66⅜	49⅜	64⅜	64⅛	62½	60½	62½
1858	39⅜	56⅜	40⅜	56½	53½	57⅜	52	57⅜
1859	21½	35⅜	20⅜	35½	38½	41	34⅛	35
1860	25⅜	43½	30⅜	46½	31⅜	36⅜	35½	40⅜
1861	35	55⅜	36⅞	55⅞	56⅜	56⅜	51⅜	53⅜
1862	31⅛	51	36½	48⅜	41	45	36	46½
1863	49	60½	54	59½	51⅞	55	53⅛	54⅜
1864	41⅜	56⅞	44⅜	56⅜	48⅛	51⅜	49⅜	53
1865	33½	47⅛	34⅜	48⅜	45	46⅜	48½	48½
1866	29½	50⅞	29⅜	50⅜	45⅞	47⅞	43½	48⅜
1867	29⅜	44⅜	32⅜	45	38⅜	45⅛	38⅜	42⅜
1868	27	44	27⅛	45⅜	37	35½	35⅛	36½
1869	32⅛	48½	33⅞	49⅛	42⅛	48½	43⅜	52⅜
1870	29½	46⅜	32⅜	44½	41½	41½	38⅜	43½
1871	39⅛	46⅜	36⅜	46	44	41½	45⅜	47⅛
1872	26⅜	38⅜	29⅜	39	30½	33½	27⅞	33⅜
1873	37½	49	33½	46⅜	45⅞	48⅜	44⅜	46⅜
1874	30½	53⅜	32	51⅜	47⅜	49⅜	45⅜	49½
1875	29½	38⅜	27½	42⅜	38½	42⅜	33⅜	44½
1876	19½	31⅜	22½	36⅜	36⅜	34½	31	35
1877	37½	46⅜	36½	49½	44½	42⅜	45½	47⅛
1878	15⅞	33½	20½	31½	27½	32	29½	32½
1879	13⅜	26⅜	16⅜	25½	27½	26½	26⅜	31⅜
1880	38½	57½	41⅜	59⅜	50½	55⅞	51⅜	54⅞
1881	34⅜	43½	36½	47½	41⅜	47⅜	40½	45
1882	34½	46½	36⅜	50⅜	44⅜	48½	44⅜	46⅜
1883	43½	53½	44½	54⅜	46	49	44⅜	48½
1884	34½	43⅜	33½	45½	40	43½	38½	40⅜
1885	17⅜	38⅜	21⅞	31⅜	28⅜	34	26⅜	32⅜
AVERAGES								
4 yrs. 1852-55	47⅜	49⅞	45½	50½	47	46⅝	43½	47⅜
,, 1856-59	36⅜	47⅛	34	48⅜	48⅜	49⅜	44⅜	47⅛
,, 1860-63	35½	52⅜	39½	52⅜	45½	48⅜	45⅞	48⅜
,, 1864-67	33⅜	49⅞	35⅞	50½	44⅜	47½	45½	49⅜
,, 1868-71	31⅞	46½	32⅜	46⅞	41⅜	41½	40⅜	44⅜
,, 1872-75	31	45	30⅜	43½	40½	43⅜	37⅛	43½
,, 1876-79	21½	34⅜	24½	35⅜	34	34½	32⅜	36½
,, 1880-83	37½	50	39⅜	53	45⅜	50½	45⅜	48⅜
8 yrs. 1852-59	42½	48⅜	39⅜	49⅜	47⅜	48	44½	47⅜
,, 1860-67	34⅜	51½	37⅜	51½	44⅜	48	44⅜	48⅜
,, 1868-75	31⅜	45⅜	31⅜	44⅜	40⅞	42⅜	39½	44⅜
,, 1876-83	29⅜	42½	32	44⅜	39½	42⅜	39	42⅜
16 yrs. 1852-67	38½	50	38⅜	50½	46½	48	44⅜	47⅞
,, 1868-83	30½	44	31½	44⅜	40⅜	42½	39⅜	43⅜
32 yrs. 1852-83	34⅜	47	35½	47½	43½	45½	41⅜	45⅜
P.C. Reduction 2nd 16 yrs.	20·3	12·0	17·8	11·6	12·7	11·5	11·8	9·4

(1) 6 yrs. 1852-7, Amm. Salts 400 lbs; 10 yrs. 58-67, 200 lbs; 1868 and since, 275 lbs. Nitrate soda.
(2) 6 yrs. 1852-71 Rape Cake 2000 lbs., and since 1000 lbs.

purely mineral manures, of purely nitrogenous manures, and of combinations of the two.

Results are given for sixteen plots, arranged in four series of four plots each, and for each plot the produce—dressed grain per acre—is given for thirty-four years in succession.

Series 1 comprises four plots, without any nitrogenous manure, namely—

Plot 1.—Without manure.
,, 2.—Superphosphate of lime alone.
,, 3.—Sulphates of potash, soda, and magnesia.
,, 4.—Superphosphate, and sulphates of potash, soda, and magnesia.

Series 2 comprises four plots, with the same four conditions as to mineral manures as Series 1, and ammonium salts supplying 43 lbs. of nitrogen per acre, per annum, in addition.

Series 3, the same four conditions as to mineral manure, with for six years 86 lbs., and for ten years 43 lbs. of nitrogen per acre per annum as ammonium salts, and for the last eighteen years 43 lbs. as nitrate of soda.

Series 4, the same four conditions as to mineral manure, with 2,000 lbs. rape cake per acre per annum, in the first six years; and 1,000 lbs. each year since.

It may be mentioned that 1,000 lbs. rape cake will, on the average, contain 48 to 50 lbs. of nitrogen, or rather more than in the amounts of ammonium-salts, or nitrate used, though probably not more is rendered available within the years of application, but there will obviously be accumulation, and some cumulative action from year to year.

Time will not allow me to call your attention in any detail to the produce of individual years, but you will observe that under all conditions of manuring, whether without nitrogenous supply as in Series 1, or with it, in the different forms and combinations, as in the other Series, there is great fluctuation from year to year, according to season. Thus, without manure the produce ranges from 35 bushels in 1854, to only 6¼ bushels in 1879; with a full mineral manure (plot 4, Series 1) from 42 bushels in 1854 to 7¼ bushels in 1879; with the full mineral manure and ammonium salts (plot 4, Series 2) = 43 lbs. nitrogen, from 60⅝ bushels in 1854 to 27⅜ in 1879.

As in the cases of Series 3 and 4, more nitrogen was applied during the first six years than afterwards, the comparison of the produce in individual years at the beginning and at the end of the period have not quite equal significance; but it may be observed that with the full mineral manure and ammonium salts at first, and nitrate of soda afterwards (plot 4, Series 3), the produce varied from nearly 65 bushels in 1857 to 25½ bushels in 1879; and lastly, with the full mineral manure and rape cake it ranged from 62¼ bushels in 1857 to 31⅛ bushels in 1879.

Looking to the average produce of each of the eight four-yearly periods, it is seen that, under all conditions of manuring, even in the case of the rape cake with its annual accumulation, there is a general

tendency to reduction in produce from the first to, and especially in, the seventh period, 1876 to 1879; but there is as uniformly an increase over the eighth period, 1880 to 1883. There is in these facts clear evidence that the previous reduction was, independently of exhaustion in individual cases, mainly due to the seasons.

The bottom line of the Tables, which shows the percentage reduction in the amount of produce over the second 16 years compared with the first 16, enables us to discriminate in some degree between the effects of exhaustion and those of season.

It is seen that the four plots of Series 1 show a reduction over the second 16 years from about 31 to 34 per cent., or more than twice as much as in the case of either of the other Series. There is here evidence that in the case of Series 1, without nitrogenous manure, much of the reduction over the second half of the period was due to nitrogen-exhaustion.

In Series 2, with ammonium salts, there is 16 per cent. reduction on plot 1, where the ammonium salts are used alone, and only from 10 to 12 per cent. where mineral manures are used in addition.

In Series 3, with nitrate of soda, there is a reduction of 20 per cent. where the nitrate is used without mineral manure, of nearly 18 per cent. where it is used with potash, soda, and magnesia, but without phosphate (plot 3), and of only about 12 per cent. where phosphates were used in addition to the nitrate.

Lastly, in Series 4, with rape cake, which contains a considerable amount of mineral matter, there is a reduction of only 12·7 per cent. where it is used alone, of less where any mineral manure is used in addition, and of only about 9½ per cent. where a full mineral manure is also used.

As already intimated, that there should be any reduction in the yield over the second half of the period where rape cake, with its annual residue and accumulation, is used, is evidence that part of the reduction is due to an average of less favourable seasons over the later period. But that there should be the greatest reduction in Series 1, where no nitrogen is supplied, is evidence of nitrogen-exhaustion under those conditions; and that within Series 2 and 3 respectively there should be the greatest reduction, where the ammonium salts or nitrate are used without phosphates, is evidence of phosphoric-acid exhaustion in those cases.

Leaving the results relating to the produce of each individual year, or of limited series of years, as given in Tables II. and III., a general view of the effects of the sixteen different conditions as to manuring is conveniently obtained in the *Summary Table* IV. (p. 12). There is there given the average produce over the thirty-two years on each of the sixteen plots. The first column gives the results for the four plots of Series 1, without nitrogenous manure; the second column those for Series 2, with ammonium salts equal to 43 lbs. nitrogen per acre per annum; the third those for Series 3, with nitrate of soda; and the fourth those for Series 4, with rape cake. The upper division of the Table gives,

for each plot, the average produce of grain per acre in bushels; the middle division, the average produce of straw in lbs.; and the lower division, the average total produce (corn and straw together) in lbs.

TABLE IV.

Barley 32 years in succession on the same land—Hoosfield, Rothamsted.

SUMMARY.

Showing the effects of exhaustion and manures.

	No Nitrogenous Manure	200 lbs. Am. Salts = 43 lbs. N	275 lbs. N. Soda (1) = 43 lbs. N	1000 lbs. R. Cake (2) = 49 lbs. N
DRESSED GRAIN per acre. Bushels				
Without Mineral Manure	17⅞	30¾	34⅜	43½
Superphosphate	23	45	47	45¾
Sulphates Potash, Soda, and Magnesia ...	19¾	33⅜	35½	41¾
Superphosphate and Sulphate Potash, Soda, and Magnesia	24½	44⅞	47½	45⅜
STRAW, per acre. Lbs.				
Without Mineral Manure	1128	1909	2246	2789
Superphosphate	1293	2827	3127	2953
Sulphates Potash, Soda, and Magnesia ...	1170	2151	2455	2792
Superphosphate, and Sulphates Potash, Soda, and Magnesia	1380	3019	3348	3065
TOTAL PRODUCE (GRAIN and STRAW), per acre. Lbs.				
Without Mineral Manure	2136	3649	4189	5249
Superphosphate	2584	5374	5791	5532
Sulphates Potash, Soda, and Magnesia ...	2278	4063	4490	5175
Superphosphate, and Sulphates Potash, Soda, and Magnesia	2739	5574	6042	5667

(1) Ammonium-Salts = 86 lbs Nitrogen first 6 years, = 43 lbs next 10 years; Nitrate Soda = 43 lbs Nitrogen last 16 years. (2) 2000 lbs Rape Cake first 6 yrs. 1000 lbs since.

Referring first to the results on the four plots without nitrogenous manure, as given in the first column of the Table, it is seen that plot 2, with superphosphate of lime, and plot 4, with superphosphate and salts of potash, soda and magnesia, give considerably more produce than plot 3, with the potash, soda, and magnesia, without phosphate. There is more of straw, as well as grain, and of course, therefore, of total produce, with than without the phosphate. There is, indeed, very marked effect by phosphatic manure, and very little by the alkalies.

The second column, with the same four conditions as to mineral supply, but with, in each case, 43 lbs. of nitrogen per acre per annum as ammonium salts, shows a very great increase. Even with the ammonium salts alone there is a great increase; there is somewhat more on plot 3, where the alkalies are also applied, but very much more still on plots 2 and 4, where phosphates are also used.

The third column shows that with a larger amount of nitrogen supplied in the first six years, and with nitrate of soda instead of ammonium salts in the later years, there is still greater increase; and again, the increase is by far the greater where the superphosphate is used.

The four plots of Series 4, with the rape cake, show a much greater uniformity of result with the different mineral manures. Still the two phosphate plots (2 and 4) give more produce than the two without phosphate. Referring to the produce of grain in illustration, it is seen that plots 1 and 3 without phosphate give considerably more produce than the same plots (1 and 3), in either Series 2 with the ammonium salts, or in Series 3 with the nitrate of soda. The explanation of this is that the rape cake itself contains phosphates. On plots 2 and 4, on the other hand, where phosphates are added, there is nearly as much produce in Series 2 with the ammonium salts, and more in Series 3 with the nitrate, than in Series 4 with the rape cake.

Thus, then, whilst there is evidence that the phosphate of the rape cake was effective when none was otherwise supplied, when it was so applied in addition there was more effect with the nitrate, with its more rapidly available nitrogen, than with the rape cake, with its greater actual amount of nitrogen, but in a less rapidly available condition.

Comparing the produce of plot 2 with superphosphate without potash, with that of plot 4 with superphosphate, and salts of potash, soda and magnesia in addition, it is remarkable that, both in Series 2 with the ammonium salts, and in Series 3 with nitrate of soda, there is over the whole period of thirty-two years almost identically the same amount of barley grain without as with the potash. There is, however, rather more straw and total produce with than without the potash. Thus we have, with the ammonium salts, an average of forty-five bushels without potash, and 44⅞ bushels with potash; and with the nitrate of soda 47 bushels without, and 47½ bushels with potash. Of straw, however, there is, with the ammonium salts, an average of 2,827 lbs. without, and 3,019 with the potash; and on the nitrate plots 3,127 lbs. without, and 3,348 lbs. with potash.

It will afterwards be seen that where nitrogen and phosphoric acid were liberally supplied without potash, the available potash of the soil itself became deficient; though this deficiency was to the last scarcely at all manifested in the produce of grain. It is obvious, however, that with gradual reduction in the amount of plant, the yield of grain must in time diminish.

So much for the influence on the barley crop, of different conditions of manuring, each continued for more than thirty years on the same plot, and in a field of somewhat heavy loam, with a raw clay subsoil, and chalk below, giving good natural drainage.

It is seen that nitrogenous manures alone had much more effect than mineral manures alone. It was obvious, therefore, that the exhaustion induced by the continuous growth of the crop was characteristically that of nitrogen.

Both with and without nitrogenous supply phosphates were more effective than potash salts, showing that the available store of phosphoric acid in the soil became deficient sooner than that of potash. With the shorter period of growth of barley than of wheat, and its greater proportion of surface-rooting, both nitrogenous and mineral exhaustion

are sooner developed; and so far as mineral exhaustion is concerned, the available supply of phosphoric acid was sooner exhausted than was that of potash. Indeed, in ordinary agricultural practice, it is clearly established that superphosphate is more effective with the spring-sown than with the autumn-sown cereals.

Influence of Season on the Amounts of Produce.

It has been seen that there were, under all conditions of manuring, very great variations in the amount of produce from year to year according to season. The extent and character of the influence of season will be brought prominently to view by comparing the produce of the best and the worst seasons of the thirty-two, and comparing the characters of the seasons themselves.

Tables V. and VI. illustrate these points. Table V. (p. 15) gives the produce of grain, the weight per bushel of the grain, the produce of straw, and the total produce (corn and straw together), of six very different conditions as to manuring in each of the best two seasons, and in the worst season of the whole series. There is also given the deficiency of produce in the bad season, compared with that in each of the two good seasons.

For wheat, 1863 was the best season of the thirty-two—indeed of the forty—of its growth. For barley, 1863 was also a very good year for both grain and straw; but it was not so good for such a variety of manures as were 1854 and 1857, which (in the Table) are adopted as the best seasons.

For almost all conditions of manuring, 1854 was the season of the highest total produce, corn and straw together; that is it was the season of the greatest luxuriance or vegetative activity. But 1857 was, especially for the highest manuring, the one of the highest produce of grain, and of the highest quality or maturity of grain, as evidenced by the weight per bushel. Thus 1854 was the highest for luxuriance, and 1857 the highest for the maturation of the crop.

As for wheat, so for barley, 1879 was decidedly the worst season of the thirty-two.

The plots selected for illustration are those without manure, with farmyard manure, with mixed mineral manure alone, with mixed mineral manure and ammonium salts, with mixed mineral manure and nitrate of soda, and with mixed mineral manure and rape cake.

It is not necessary to detain you with any detailed consideration of the results—the figures speak for themselves. The lower division of the Table shows that under each of the six very different conditions as to manuring, 1854 yielded a much higher total produce (grain and straw together) than 1857. But the upper division shows that, notwithstanding the less amount of plant, 1857 gave in most cases nearly as much grain as 1854, and in two cases—those with the highest nitrogenous manuring—(and both years were within the first six when the larger amounts were applied), 1857 gave more grain than 1854. The weight per bushel of the grain was also higher in 1857, on all the plots where nitrogenous manures were used.

The contrast between the produce in these two very different good years, and that in the worst season 1879, is very striking, the difference amounting in several cases to as much as the average crop of the country.

TABLE V

Barley, year after year on the same land, Hoosfield, Rothamsted.

Produce of the two best seasons, 1854 and 1857; of the worst season, 1879; and average of 32 years, 1852-1883

Plots	DESCRIPTION OF MANURES; QUANTITIES PER ACRE.	Best Seasons		Worst Season	1879 + or −		Average 32 Years
		1854	1857	1879	1854	1857	
	DRESSED GRAIN per acre, BUSHELS						
1o	Unmanured	35	26¼	6½	−28½	−19½	17½
7-2	Farm-yard Manure	56⅜	51½	36¾	−19⅝	−14⅝	49½
4o	Mixed Mineral Manure, alone...	42	39⅜	7½	−34½	−32⅜	24½
4a	Mix. Min. Man. and 200 lbs Amm. Salts=43 lbs N	60⅝	57⅜	27⅜	−33¼	−30	44⅜
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	62½	64½	25½	−37	−39⅛	47½
4c	" " " and 1000 lbs Rape Cake=49 lbs N	60½	62½	31⅛	−29⅛	−31⅛	45⅝
	WEIGHT PER BUSHEL OF DRESSED GRAIN, LBS						
1o	Unmanured	53·6	52·0	48·8	−4·8	−3·2	52·2
7-2	Farm-yard Manure	53·9	54·2	50·5	−3·4	−3·7	54·3
4o	Mixed Mineral Manure, alone...	54·0	53·7	50·4	−3·6	−3·3	53·2
4a	Mix. Min Man. and 200 lbs Amm. Salts=43 lbs N	54·3	54·8	50·2	−4·1	−4·6	54·2
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	52·1	53·9	49·8	−2·3	−4·1	53·8
4c	" " " and 1000 lbs Rape Cake=49 lbs N	52·8	54·1	49·6	−3·2	−4·5	53·9
	STRAW per acre, LBS						
1o	Unmanured	2442	1425	526	−1916	− 899	1128
7-2	Farm-yard Manure	4171	2649	3645	− 526	+ 996	3298
4o	Mixed mineral Manure, alone...	2595	1920	491	−2104	−1429	1380
4a	Mix. Min. Man. and 200 lbs Amm. Salts=43 lbs N	4530	3120	2333	−2197	− 787	3019
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	5487	4067	2398	−3089	−1659	3348
4c	" " " and 1000 lbs Rape Cake=49 lbs N	4712	3705	2588	−2124	−1117	3065
	TOTAL PRODUCE (Grain and Straw) per acre, LBS						
1o	Unmanured	4405	2978	943	−3462	−1935	2186
7-2	Farm-yard Manure	7298	5564	5734	−1574	+ 160	6140
4o	Mixed Mineral Manure, alone...	4969	4111	879	−4090	−3232	2739
4a	Mix. Min. Man. and 200 lbs Amm. Salts=43 lbs N	7958	6336	3867	−4091	−2469	5574
4aa	" " " and 275 lbs Nit. Soda=43 lbs N ...	9026	7734	3819	−5207	−3915	6042
4c	" " " and 1000 lbs Rape Cake=49 lbs N	8125	7241	4246	−3879	−2995	5667

NOTE.—Plot 4aa, Ammonium-Salts=86 lbs Nitrogen first 6 years, = 43 lbs next 10 years; Nitrate Soda=43 lbs Nitrogen last 16 years. Plot 4c, 2000 lbs Rape Cake first 6 years; 1000 lbs. since.

For comparison with the produce of these selected years, the average on each of the six plots over the 32 years is given; and it will be seen how very much higher than the average is the produce in the good years, and how very much lower in the bad season.

So much for the variations in the amounts of produce in the different seasons. It will be of interest to consider, however summarily

it may be practicable to do it, some of the climatic characteristics of these various seasons.

The next Table (VI.) shows, for each month of each of the three seasons, reckoning from October to September, the mean temperature, and the rainfall, above or below the average.

Table VI

Characters of the two Best Seasons, 1854 and 1857, and of the Worst Season, 1879
Temperature and Rainfall + or — Average

	Mean Temperature			Rainfall			Days of Rain, 0·01 inch, or more		
	Best two		Worst	Best two		Worst	Best two		Worst
	1854	1857	1879	1854	1857	1879	1854	1857	1879
	Deg. F	Deg. F	Deg. F	Inches	Inches	Inches	Days	Days	Days
October	+1·3	+2·1	+1·9	+1·43	—0·89	—1·14	+13	— 4	— 1
November	—0·2	—1·6	—2·6	—0·45	—1·15	+1·05	— 2	— 3	+ 2
December	—5·2	+1·0	—5·5	—1·30	—0·27	—0·94	0	+ 1	+ 4
January	+2·4	0·0	—4·7	—0·60	+0·60	+0·59	+ 3	+ 7	0
February	+0·8	+0·5	—0·5	—0·29	—1·30	+2·32	— 3	— 8	+10
March	+2·7	+0·7	+0·1	—1·28	—0·77	—1·00	— 6	— 2	+ 2
April	+2·3	—0·4	—2·9	—1·11	—0·30	+0·90	— 4	+ 7	+ 5
May	—1·6	+1·5	—4·1	+1·51	—1·67	+1·36	+ 5	— 6	+ 4
June	—2·3	+3·8	—1·3	—0·99	+0·80	+2·39	+ 1	— 2	+ 9
July	—1·3	+2·9	—3·5	—0·85	—1·50	+1·12	+ 4	— 2	+ 8
August	0·0	+4·9	—1·0	+0·21	+0·10	+2.79	+ 1	0	+ 9
September	+1·6	+3·2	—0·2	—1·42	+1·00	+0·47	— 3	+ 1	+ 2
Averages		+1·5	—2·0						
Totals				—5·14	—5·35	+9.91	+ 9	—11	+54

It is obvious that different seasons will differ almost infinitely at each succeeding period of their advance, and that, with each variation, the character of development of the plant will also vary, tending to luxuriance, or to maturation, that is, to quantity, or to quality, as the case may be. Hence, only a very detailed consideration of climatic statistics, taken together with careful periodic observations in the field, can afford a really clear perception of the connection between the ever-fluctuating characters of season, and the equally fluctuating characters of growth and produce. It is, in fact, the distribution of the various elements making up the season, their mutual adaptations, and their adaptation to the stage of growth of the plant, which, throughout, influence the tendency to produce quantity or quality. Still, it will be seen that the limited summary of the meteorological conditions of the seasons in question, which can alone be given here, is not without significance.

First then as to 1854, the season of great luxuriance and high total produce. The Table shows that there was an excess of temperature in January, February, March, and April, with a deficiency of rain from November to April inclusive; but that during May, June, and July,

that is the months of active above-ground growth, there were lower than the average temperatures, with a considerable excess of rain in May, and then a deficiency—conditions obviously favouring continued vegetation and slow maturation.

In 1857, there was less excess of temperature, and less than the average amount of rain to the end of April; then from May to August inclusive there was both considerable deficiency of rain and considerable excess of temperature; that is, there were throughout the period of active above-ground growth conditions favouring seeding tendency and maturation rather than luxuriance.

Thus, then, the two good seasons were very different in their climatic characteristics, as they were in the character of their produce.

Compared with these, the very bad season of 1879 shows much lower than average temperatures throughout the winter, spring, and summer, and even somewhat in the autumn, with, at the same time, great excess of rain from January to September inclusive; and it will be seen that both the deficiency of temperature and the excess of rain were very marked from April to August inclusive, that is, during the whole period of the above-ground growth, and the ripening, if such it may be called, of the crop, for in many cases the weight per bushel was less than 50 lbs., whilst the amounts of produce were, as has been seen, very greatly below the average.

Even then this very incomplete record of the climatic characters of the three seasons is sufficient clearly to indicate the connection between such conditions, and the characteristic differences in the three crops.

Influence of Exhaustion, Manures, and variations of Season, on the Composition of the Barley Crop.

I have now considered the influence of exhaustion, manures, and variations of season, on the *amount of produce* of Barley, and I propose briefly to consider their influence on its *composition*. When discussing last year the influence of various conditions on the composition of Wheat, it was shown that although the supplies within the soil—both of nitrogen and of mineral constituents—had a very direct influence on the composition of the crop so long as it was only in the vegetative stage, yet there was nevertheless very great uniformity in the composition of the final product of the plant—the seed—provided only that it was perfectly matured. The composition of the straw, however, showed a very direct connection with the supplies by the soil. The composition of the grain, on the other hand, was materially influenced by variations of *season*. But variations of season obviously have great influence on the condition of maturation; whilst difference in maturation implies difference in organic composition—in the amount of carbohydrates (starch especially)—formed. In fact, such variations in composition imply deviations from perfect and normal maturation; and such deviations are associated not only with differences in the organic composition—the relation of the nitrogenous to the non-nitrogenous constituents—but with differences in the mineral composition also.

It follows, from what has been said, that variations in the

composition of the final and very definite product—the seed, should be much more clearly traceable to variations of season than to the variations in the supplies within the soil; in other words, than to exhaustion or manures. This was found to be very strikingly so in the case of *wheat*, and we have now to consider how far it is so with its near ally—*barley*.

The results given in Table VII. forcibly illustrate the much greater influence of variations of season than of manures, on the composition of barley grain. Complete analyses of the ash of the grain (and also of the straw) grown by different manures, each in different seasons, have been made, and taking for illustration the important and characteristic consituents, potash and phosphoric acid, the Table shows for three very different manurial conditions—

1. Without manure,
2. With farmyard manure,
3. With an artificial manure supplying liberally both nitrogen and mineral constituents—

the highest, the lowest, and the mean amounts of potash and phosphoric acid, in 1000 parts of the dry substance of the grain, and of the straw, in the different seasons.

TABLE VII.

Highest, lowest, and mean amounts of potash and phosphoric acid per 1000 *dry substance.*

		Per 1000 Dry Grain					Per 1000 Dry Straw				
		Highest		Lowest		Mean	Highest		Lowest		Mean
POTASH.											
1 0	Unmanured ...	1871	7·66	1853	6·00	6·54	1871	11·77	1856	5·25	8·55
7 2	Farm-yard Man....	1871	8·36	1856	5·89	6·81	1871	22·01	1856	6·76	13·23
4 A	Mix. Min. Man. and Amm. Salts.	1871	7·98	1852	5·62	6·61	1871	22·53	1852	5·67	14·05
PHOSPHORIC ACID.											
1 0	Unmanured ...	1852	10·08	1854	8·85	9·27	1856	2·60	1863	1·20	1·74
7 2	Farm-yard Manure	1871	10·50	1854	9·23	9·99	1856	2·92	1863	1·48	2·19
4 A	Mix. Min. Man. and Amm. Salts....	1856	10·39	1863	8·84	9·58	1856	3·12	1863	1·06	1·94

First as to the amounts of potash in 1000 parts dry substance of grain of the differently manured plots in the different seasons. It is seen that there is much greater variation in the proportion of potash in different seasons with the same manure, than there is with different manures. Further, the seasons showing the highest amount of potash are those of much higher maturing character than those with the lowest amounts.

Next it is seen that there is still greater, indeed enormous variation, in the amount of potash in the dry substance of the straw with the

same manure, in different seasons. There is also great variation according to manure; comparatively little when there was full supply, but considerable without manure, that is with exhaustion.

Turning now to the phosphoric acid in the grain: there is here again much more variation in different seasons with the same manure, than with different manures. But whilst in the case of potash there is the higher proportion in the *better* seasons, in that of phosphoric acid there are lower amounts in the dry substance in the *better* seasons. In fact high amount of potash in the ash, and in the dry substance of the grain, is as a rule associated with high maturation, that is with high proportion of starch, whilst high proportion of phosphoric acid is generally associated with low maturation and high proportion of nitrogen.

The proportion of phosphoric acid in the straw, also varies more with season than with manure, and it is the highest in the worst seasons.

The connection between maturation and composition is further illustrated in the results given in Table VIII.

TABLE VIII.

General character of the produce, mean percentage in pure ash, and parts per 1000 *dry matter, of Potash and Phosphoric Acid. Mean of* 6 *differently-manured plots in each season. Harvests in order of highest weight per bushel.*

Harvests	Weight per bushel of Grain lbs.	Per cent. Ash (pure) in dry matter	Per cent. in Ash (pure)		Per 1000 dry matter.	
			Potash	Phosphoric Acid	Potash	Phosphoric Acid
GRAIN						
1871	55·9	2·65	29·80	35·33	7·89	9·39
1863	55·3	2·55	26·59	35·80	6·78	9·15
1852	51·7	2·48	23·84	40·69	5·90	10·13
1856	47·4	2·44	24·21	41·35	5·89	10·09
STRAW						
1871	55·9	6·27	26·01	3·68	16·57	2·31
1863	55·3	5·48	24·91	2·29	13·99	1·26
1852	51·7	4·45	14·62	4·05	6·58	1·81
1856	47·4	4·49	13·51	6·42	6·10	2·89

In the Table are given the mean results for six differently manured plots, in each of four very different seasons, so far as the maturation of the grain was concerned. The different seasons are given in the order of the highest weight per bushel of the grain—high weight per bushel being upon the whole the best practical measure of high quality.

It will be seen that, as so measured, the seasons are given in the following order—1871, 1863, 1852, and 1856,—the average weight per bushel of the grain being in 1871, 55·9 lbs.; in 1863, 55·3 lbs.; in 1852, 51·7 lbs.; and in 1856 only 47·4 lbs.; or about 8 lbs. less than

in the two seasons of highest weight. There is here, then, very great variation in the character of these four seasons, and in the degree of maturation of the grain accordingly.

The particulars of composition given for each of these four seasons are—the percentage of total mineral matter, or ash, in the dry matter of the grain, and of the straw; the percentage in the ash (of both grain and straw), of potash and phosphoric acid; and the amount of potash and phosphoric acid, in 1000 dry substance of both grain and straw.

No determinations of nitrogen are available, but it may be stated that the percentage of nitrogen is almost uniformly lower in the seasons of high maturation.

The Table shows that, in both grain and straw, there is a higher percentage of ash in the dry substance, the higher the quality of the grain. There are also higher percentages of potash, but lower percentages of phosphoric acid, in both the ash and the dry substance, the higher the quality of the grain.

In wheat, however, there is lower, not higher, percentage of ash in the dry substance of the grain, the higher its quality. But, in wheat, as in barley, there is higher percentage of potash, and lower percentage of phosphoric acid, in the ash, the higher the quality. On the other hand, there is not in the case of wheat, as there is in barley, a much higher percentage of potash in the dry substance, the higher the quality. This difference may be partly due to the larger proportion of starch to nitrogenous substance in the barley; but it is probably in part also due to the paleæ (or chaff) of the barley, but not of the wheat, being adherent, and retaining the surplus potash brought up for grain formation.

In both descriptions of grain there is very uniformly a lower proportion of phosphoric acid in the dry matter, the higher the quality of the grain.

In the straw, there is high percentage of ash in the dry matter, high percentage of potash, and low percentage of phosphoric acid, in the ash, and high percentage of potash, and low of phosphoric acid, in the dry matter, the higher the quality of the grain. In the straw, however, the variations show a much wider range, indicating much less definiteness, and greater irregularity in condition.

Thus, then, the higher the quality of the barley grain, that is the higher its proportion of starch, the higher is the proportion of potash, and the lower is that of phosphoric acid. It may be mentioned that with a higher proportion of potash there is generally a lower proportion of both lime and magnesia, and with a lower proportion of phosphoric acid there is a somewhat higher proportion of sulphuric acid.

Another point of interest is, although it is true the amounts are small, that there is a tendency to a higher proportion of soda in the grain ash, and in the dry matter of the grain, in the better seasons, even when there is no deficiency of potash. This, again, is probably due to the ash of the barley grain containing that of the adherent paleæ.

In relation to the composition of the straw, the most striking result is (though not shown in the Table) that there is little more than two thirds as high a percentage of silica in the ash of the produce of the better as in that of the worse seasons.

Thus far the effects of season, and coincidently with this the degree of maturity of the grain, on its composition, have chiefly been illustrated. The next results illustrate more directly the influence of *exhaustion*, or of *full supply*, of mineral, or ash constituents, on the mineral composition of the produce, both grain and straw.

The first three columns of Table IX. (p. 22), relate to the mineral composition of the produce grown for 25 years in succession, by ammonium salts and superphosphate of lime, but without supply of potash, soda, or magnesia. The last three columns show the composition of the produce by ammonium salts, and superphosphate, with potash, soda, and magnesia, in addition. There are given the results obtained by the analysis of proportionally mixed samples of the produce, of ten years 1852-61, of ten years 1862-71, and of five years 1872-76. The upper division of the Table gives for the potash, the second for the soda, the third for the phosphoric acid, and the fourth for the silica—1, the percentage in the ash (pure) of the grain and of the straw; 2, the amounts per 1000 dry matter of grain and of straw; 3, the amounts per acre per annum in lbs. in the total produce (grain and straw together), in the grain alone, and in the straw alone.

First referring to the potash, its percentege, even in the grain ash, is seen somewhat to diminish from period to period where none was supplied in manure; and in a somewhat greater degree to increase where there was an annual supply of it by manure. In the straw ash, however, whilst the percentage of potash goes down from 18·44 over the first period to only 8·70, or less than half, over the third period, where none was supplied, it increases from 27·85 per cent. over the first, to 34·43 per cent. over the third period, when it was annually supplied. Thus, the influence of exhaustion, or of full supply, has been comparatively small on the mineral composition of the grain, but very great indeed on that of the straw.

The point is further illustrated in the next results, showing the amounts of potash, per 1000 dry matter of grain, and of straw, respectively. There is again comparatively little variation in the relation of the potash to the organic matter in the case of the grain, but very great variation in the case of the straw; and when it is borne in mind, that the ash of barley grain contains that of the adherent paleæ as well as that of the grain proper, the conclusion is that the variation in the proportion of potash to the fixed organic substance of the grain itself is much less than the figures would indicate. Indeed, it is probable that the variation, such as it is, is associated with a different relative proportion of the organic compounds themselves—of the fully matured non-nitrogenous to the nitrogenous bodies. In fact, the evidence, duly considered, is not in favour of the view that there is variation in the proportion of the potash to the fixed and ripened

non-nitrogenous constituents, with the formation of which it is associated.

Table IX

Experiments on Barley, Hoosfield, Rothamsted. Potash, Soda, Phosphoric acid, and Silica, per cent in Ash, per 1000 Dry substance, and Quantities per acre

		Ammonium salts and Superphosphate			Ammonium salts superphosphate and potash, soda, and magnesia.		
		10 years 1852-1861	10 years 1862-1871	5 years 1872-1876	10 years 1852-1861	10 years 1862-1871	5 years 1872-1876
POTASH							
Per cent in Ash	of Grain	26·79	25·97	25·37	27·62	28·46	29·19
	of Straw	18·44	13·31	8·70	27·85	32·92	34·43
Per 1000 Dry Matter	of Grain	6·22	6·23	5·68	6·52	6·89	7·11
	of Straw	8·54	6·41	3·63	14·65	18·51	17·88
Per acre per annum. lbs	in Total Produce	35·60	30·68	18·16	53·74	63·73	53.05
	in Grain	13·07	14·45	11·33	13·80	15·28	13·87
	in Straw	22·53	16·43	6·83	39·94	48·45	39·18
SODA							
Per cent in Ash	of Grain	1·15	2·07	2·72	0·51	0·58	0·66
	of Straw	6·42	11·39	15·53	2·50	2·30	2·60
Per 1000 Dry Matter	of Grain	0·27	0·50	0·63	0·12	0·14	0·16
	of Straw	2·97	5·49	5·65	1·32	1·29	1·35
Per acre per annum. lbs	in Total Produce	8·40	15·21	11·85	3·84	3.69	3·27
	in Grain	0·56	1·15	1·22	0·25	0·31	0·31
	in Straw	7·84	14·06	10·63	3·59	3·38	2·96
PHOSPHORIC ACID							
Per cent in Ash	of Grain	38·55	36·36	38·20	38·53	37·31	36·61
	of Straw	3·06	2·55	3·48	2·97	2·47	3·15
Per 1000 Dry Matter	of Grain	8·95	8·72	8·85	9.10	8·95	9·39
	of Straw	1·42	1·23	1·45	1·56	1·39	1·63
Per acre per annum, lbs	in Total Produce	22·54	23·38	19·78	23·51	23·67	21·91
	in Grain	18·80	20·23	17·05	19·25	20·04	18·33
	in Straw	3·74	3·15	2·73	4·26	3·63	3·58
SILICA							
Per cent in Ash	of Grain	18·60	20·62	18·64	18·67	19·18	17·14
	of Straw	47·87	43·39	44·07	43·67	35·41	32·02
Per 1000 Dry Matter	of Grain	4·32	4·95	4·32	4·41	4·60	4·17
	of Straw	22·16	20·92	18·37	22·96	19·91	16·63
Per acre per annum, lbs	in Total Produce	67·55	65·05	42·92	71·96	62·42	44·58
	in Grain	9·07	11·47	8·32	9·33	10·30	8·14
	in Straw	58·48	53·58	34·60	62·63	52·12	36·44

The effects of exhaustion, or of full supply of constituents, is more strikingly still brought out by a study of the figures showing the amounts of potash taken up per acre by the crops without, and with, the supply of it. Thus, the average amounts of potash taken up, or rather retained, per acre per annum, in the entire crop (grain and straw together) are, over the three successive periods, without supply of it—35·60, 30·88, and 18·16 lbs.; and with full supply they are, over the same periods—53·74, 63·73, and 53·05 lbs. That is to say there is without supply little more than half as much potash annually stored up in the crop over the last five years, as over the first ten years, of the 25. On the other hand, with full supply, there is, over the second period more than, and over the third period about the same amount as, over the first period; and there is, over the first period about one-and-a-half time, over the second period twice, and over the third period nearly three times, as much as where there was no supply.

Yet, with these enormous differences in the amounts taken up and retained by the entire plant in the different cases, there is comparatively little difference in the amounts accumulated in the grain. Thus, over the first period, the amounts in the grain are—without supply 13·07 lbs., and with supply 13·80 lbs.; over the second period—without supply 14·45 lbs., and with supply 15·28 lbs.; and over the third period—without supply 11·33 lbs., and with supply 13·87 lbs.

It is thus seen that, over each period, there was rather less in the grain without than with supply, but that the deficiency was not material until the third period; that is until after 20 years without supply in the one case, and 20 years with it in the other.

In reference to these results, it has already been shown, in discussing those in Table IV. (p. 12) that over a period of 32 years, that is extending seven years later than the 25 years to which the foregoing figures relate, there was almost identically the same amount of produce of grain, without as with the supply of potash; though there was, on the other hand, rather more straw, especially in the later years, with the supply. It would appear, therefore, that the diminished amount of potash taken up by the plant was sufficient for the exigencies of grain-formation almost to the end of the period; and that at least a large proportion of the excess taken up when it was liberally supplied was surplusage so far as the requirements of the grain were concerned. Some idea of how great was this surplusage may be formed by reference to the difference in the amounts of potash eventually remaining in the straw. Thus, the average amounts of potash per acre per annum in the straw were—over the first period, without supply, 22·53 lbs., and with supply 39·94 lbs., or 17·41 lbs. more; over the second period, without supply 16·43 lbs., and with supply 48·45 lbs., or 32·02 lbs. more; and over the third period, without supply 6·83 lbs., and with supply 39·18 lbs., or 32·35 lbs. more. It is not to be supposed, however, that the whole of these plus-amounts were surplusage; for although the average yield of grain has been so well maintained, the character of the plant has obviously depreciated for a good many years,

and several times in recent years even the yield of grain has been considerably deficient. Indeed, it would seem that the plant has become more sensitive to adverse conditions of soil or season.

Turning now to the soda, it is seen that whether we look at its percentage in the ash of the grain, and of the straw, its proportion in 1000 dry substance, or the amounts in the acreage crops, very much more was found in the crops grown without its supply, but where potash was deficient, than where soda was annually supplied. This is strikingly illustrated by reference to the average amounts per acre per annum in the total crops, grain and straw together. Thus, over the first period, the average amounts of soda in the total crop were, without any supply of either potash, soda, or magnesia, 8·40 lbs., and with the supply of all three, only 3·84 lbs.; over the second period, without the supply 15·21 lbs., and with the supply only 3·69 lbs.; and, lastly, over the third period, without the supply 11·85 lbs., and with the supply only 3·27 lbs.

Thus, then, not only was there much more soda taken up, or retained, by the plant where it was not supplied than where it was, but it is evident that there was the more soda taken up the less the supply of potash. The amounts of soda retained in the grain are, however, seen to be but small; there is more it is true where there was a deficiency of potash, and where more soda was taken up. But, looking to the amounts of soda per cent. in the grain ash, or per 1000 dry substance of the grain, it would seem probable that the larger amounts where there was deficiency of potash, and more total soda taken up, were probably only due to larger amounts eliminated from the grain proper, and retained in the adherent paleæ, or chaff. Whether, however, the soda has been of any avail, in the earlier, or merely vegetative stages of growth, as a carrier, or otherwise, may be a question.

Next as to the phosphoric acid, of which there was the same annual supply on both plots. It is seen that whether we take its percentage in the ash, its proportion to the dry substance, or its average quantity per acre, the amounts are, in the comparable cases, comparatively uniform; the differences not being greater than can be supposed to be connected with the differences in growth due to the differences in the supply of other constituents.

Lastly, as to the silica: the chief point of interest to remark is, that, as the figures show, its percentage in these barley grain ashes ranges from 17 to more than 20, whereas in wheat grain ash it ranges only from about 0·5 to about 1·5 per cent.; or, if we take the proportion of silica to 1000 dry substance of grain, in barley it ranges from 4 to 5 parts, and in wheat only from about 0.1 to about 0.3 parts. This difference is obviously due to the chaff being adherent in the case of barley, and not in that of wheat; and the figures afford clear illustration of the material degree in which the composition of barley grain-ash is influenced by the inclusion in it of what is, in a sense, extraneous matter. It is indeed obvious that, under such circumstances, we should

expect, as we find, less definiteness in the mineral composition of the grain of barley than in that of wheat.

On what does Strength of Straw depend?

It will be appropriate to refer here to the bearing of experimental evidence on the question whether, as is frequently stated, strength of straw is dependent on a high percentage of silica. Table X. (p. 26) affords illustrations on this point. The upper division of the Table gives results relating to wheat, and the lower division corresponding results relating to barley. In the case of wheat five, and in that of barley three, very different conditions of manuring are selected for illustration; and for each condition as to manuring results obtained in bad and in good seasons, are given. The particulars indicating the character of the crops are—the percentage of grain in the total produce, and the weight per bushel of the dressed grain; and side by side with these are recorded—the percentage of ash in the dry matter of the straw, the percentage of silica in the ash, and the percentage of silica in the dry matter.

In the wheat in every case, and in the barley in every case but one, there is a higher proportion of grain in the better season; and in every case, of both wheat and barley, there is a much higher weight per bushel of grain in the better season. These conditions are, in fact, proof of the superiority of the crops in the main characters of seed-forming tendency, and ripening.

The percentage of ash in the dry matter of the straw is not a very significant character; and it is seen that in the case of the wheat it was on the average somewhat the lower, but in that of the barley uniformly the higher in the better seasons.

The percentage of silica in the straw ash is more significant, and in both the wheat and the barley it is under all the conditions of manuring much the lower in the better seasons. More significant still, is the percentage of silica in the dry matter of the straw, and it is seen that, with the wheat under each condition of manuring, and with the barley under most conditions, it is considerably lower in the better seasons. It may be observed that the exceptions in the case of the barley were where organic manure, as in rape-cake and farm-yard manure, was employed.

Direct analytical results clearly show, therefore, that the proportion of silica is, as a rule, lower, not higher, in the straw of the better grown and better ripened crops.

This result is quite inconsistent with the usually accepted view that high quality and stiffness of straw depend on a high amount of silica. Pierre and Bretschneider have, however, concluded from their experiments that this is not the case, and at Rothamsted we have long maintained a contrary view. In fact, high proportion of silica means a relatively low proportion of organic substance produced. Nor can there be any doubt that strength of straw depends on the favourable development of the woody substance; and the more this is attained the more will the accumulated silica be, so to speak, diluted—in other words, show a lower proportion to the organic substance.

TABLE X.

Per cent. Silica in the Ash, and in the dry matter, of Wheat Straw and Barley Straw grown by different manures, and in different seasons.

		Per cent. Corn in Total Produce	Weight per bushel dressed corn	Per cent. Ash in dry matter	Per cent. Silica in Ash	Per cent. Silica in dry matter
WHEAT						
Without Manure	1856	36·4	54·3	5·5	71·47	3·93
	1858	40·6	60·4	4·9	65·85	3·23
Amm. Salts alone	1856	34·8	55·5	3·9	66·23	2·58
	1858	40·3	59·6	4·0	57·47	2·30
Mixed Mineral Manure	1856	36·7	56·4	5·7	68·74	3·92
	1858	43·6	61·5	5·6	64·67	3·62
Mineral Manure and Amm. Salts	1856	33·6	56·0	4·9	64·63	3·17
	1858	38·2	62·2	5·0	55·60	2·78
Farm-yard Manure	1856	34·5	58·6	6·7	69·56	4·66
	1858	39·6	62·6	6·54	59·71	3·90
BARLEY						
Rape cake	1852	44·3	51·7	4·75	57·49	2·73
	1871	45·4	56·3	5·54	42·04	2·33
Rape cake	1856	39·1	46·1	4·63	49·39	2·29
	1863	48·4	56·3	5·17	45·62	2·36
Mineral Manure and Amm. Salts	1852	43·2	51·4	4·19	62·21	2·61
	1871	43·3	56·5	6·70	32·71	2·19
Mineral Manure and Amm. Salts	1856	40·2	46·4	5·48	57·47	3·15
	1863	47·3	56·5	6·32	35·24	2·23
Farm-yard Manure	1852	47·0	52·8	5·15	57·38	2·96
	1871	43·8	56·6	7·55	42·71	3·22
Farm-yard Manure	1856	42·8	47·1	4·92	57·85	2·85
	1863	48·3	57·2	6·21	43·08	2·68

I may mention that in my own neighbourhood, where the straw-plait industry prevails, the complaint during several recent seasons of bad harvests was that an unusually large proportion of the straw was brittle, and broke in the working; and considering the character of the seasons there can be no doubt that this was associated with low development of the woody matter, and high proportion of silica.

Our Area under the Crop, and the Amount of our Imports.

Before concluding on the subject of barley, it will be of interest to consider the extent of area devoted to the crop in the United Kingdom, the amount of our total annual imports, and from what countries our supplies are chiefly derived.

Table XI. (p. 27) shows the area under the crop in the United Kingdom, in each of the last 13 years, 1873 to 1885 inclusive. It also shows the total imports into the United Kingdom during the year

succeeding each of the first 12 of the 13 harvests, reckoning from September 1 to August 31 in each case.

The figures show that since the harvest-year 1880-81, there has been a reduction of area. Further, the last column shows that since the same date there has been a considerable increase in our imports.

TABLE XI.

Area under Barley in the United Kingdom; also Imports into the United Kingdom, during each harvest year from 1873-4 *to* 1885-6.

Harvest Years	Area	Imports
	Acres	Quarters
1873-4	2,574,529	2,391,785
1874-5	2,507,130	3,667,174
1875-6	2,751,362	2,272,061
1876-7	2,762,263	3,684,725
1877-8	2,652,300	3,976,384
1878-9	2,722,879	2,798,494
1879-80	2,931,809	3,467,147
1880-1	2,695,000	2,974,692
1881-2	2,662,927	3,725,384
1882-3	2,452,077	4,398,127
1883-4	2,486,137	4,061,722
1884-5	2,346,041	4,726,908
1885-6	2,447,169	

NOTE.—The Area refers to the first of the two dates opposite to which it is placed; the Imports refer to the succeeding harvest year—September 1st to August 31st.

Now, it was in 1880 that the repeal of the malt-tax took place; a change which it was maintained by its advocates in the agricultural interest, would greatly encourage the home growth of barley. The actual result has been, however, a diminution of our own area, and an increase in our imports. It would seem that the high duty served as a bounty on the higher qualities of our own production, and that when this was removed, the greater demand for medium qualities has given an advantage to the foreign grower.

Nor has the removal of the duty led to an extended use of malt for feeding purposes, which was one of the main objects for which the repeal was strongly advocated by farmers. At Rothamsted, much careful experiment led us long ago to the conclusion that the advocacy of repeal on these grounds was illusory, and for our pains we have been accused of not being the farmers' friends! The result has, however, fully justified the view we took on the point.

Table XII. (p. 28) shows the imports of barley from different countries over the 16 civil years to 1884 inclusive. The countries are arranged in the order of their highest average supply over those years. It will be seen that both in average, and in detail in recent years, Russia is the most important source. France and Germany show fairly equal average amounts, but Germany has sent us decidedly the most in recent years. On the other hand, it is remarkable how very large was the amount sent us by France in 1872; that is just after the war.

TABLE XII.

Imports of Barley from different Countries, into the United Kingdom, 16 years—1869-1884.

Years	Russia	France	Germany	Turkey	Roumania	Denmark	Sweden	United States	Egypt	Chili	Other Countries	Total	Years
	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	Quarters	
1869	277,108	431,020	406,249	424,969	79,851	295,485	53,848	228	21,575	2,265	262,417	2,255,055	1869
1870	717,997	155,203	339,248	117,102	60,148	473,589	115,972	...	7,312	...	34,342	2,020,863	1870
1871	671,656	434,715	333,655	312,080	120,997	297,473	99,839	18,517	1,864	...	108,587	2,399,323	1871
1872	491,498	1,731,259	468,322	419,777	341,109	510,852	100,223	4,944	19,609	...	125,446	4,213,039	1872
1873	313,346	551,868	318,846	813,561	234,950	238,008	50,961	4,068	4,623	3	57,949	2,587,496	1873
1874	565,421	598,196	203,919	931,582	268,485	373,337	95,613	9,016	13,516	1,226	113,001	3,173,912	1874
1875	723,956	582,891	313 394	714,996	193,133	332,567	131,275	2,158	35,746	69,792	64,945	3,093,853	1875
1876	433,305	459,780	120,776	905,968	270,061	278,325	89,737	36,000	76,361	196	65,901	2,736,425	1876
1877	419,878	532,015	725,904	1,059,773	59,448	278,605	89,111	226,072	61,608	1,247	175,006	3,626,667	1877
1878	1,351,746	128,679	882,005	297,523	299,223	519,149	128,964	309,677	...	...	62,971	3,963,937	1878
1879	692,469	175,190	1,008,144	25,004	429,516	594,371	137,488	44,366	26,406	16,899	83,095	3,232,968	1879
1880	417,610	336,249	736,317	23,391	676,951	593,168	130,493	91,937	35,071	69,761	174,583	3,277,481	1880
1881	327,018	560,331	473,846	70,550	598,398	385,534	64,156	76,681	16,792	951	241,408	2,745,665	1881
1882	1,147,256	254,712	609,150	143,736	1,601,596	297,616	155,879	13,222	13,571	1,918	119,489	4,351,231	1882
1883	1,544,774	413,200	502,576	331,254	1,248,968	210,010	111,301	33,252	26,865	14,801	172,173	4,609,174	1883
1884	1,390,366	356,753	202,869	673,017	392,339	68,525	49,305	63,465	63,095	81,697	268,413	3,626,844	1884
Mean	717,888	480,879	477 951	458,393	420,904	358,847	100,259	57,988	26,501	16,274	133,917	3,244,746	Mean

In the above Table, the Imports are given for the Civil years, not the Harvest years.

Turkey contributes very variable quantities; as also does Roumania, which gives an average of nearly one and a half million quarters in 1882 and 1883, and little more than one-third of a million in 1884. Denmark supplies more than Sweden; but upon the whole somewhat diminishing amounts in recent years. The United States send comparatively small, and upon the whole diminishing quantities in recent years; whilst Egypt and Chili send on the average less still, but considerably increased quantities in the last year for which the records are given—1884.

Conclusion.

I have now illustrated the influence of exhaustion, of manures, and of variations of season, on the amounts of produce, and on the composition, of barley.

It has been seen that its requirements within the soil, and its susceptibility to the external influences of season, are very similar to those of its near ally, wheat; but that there are distinctions of result, dependent on differences in the habits of the plants, and in the conditions of their cultivation accordingly.

Wheat is as a rule sown in the autumn, in a heavier and closer soil, and has four or five months in which to distribute its roots and get possession of a wide range of soil and subsoil before barley is sown.

Barley is sown in a lighter surface soil, and, with its short period for root development, relies in a much greater degree on the stores within the *surface soil*. Accordingly, it is more susceptible to exhaustion of surface soil as to its nitrogenous, and especially as to its mineral supplies; and in the common practice of agriculture it is found to be more benefited by direct mineral manures, especially phosphatic manures, than is wheat when sown under equal soil conditions.

The exhaustion induced by both crops is, however, characteristically that of available nitrogen; and when, under the ordinary conditions of manuring and cropping, artificial manuring is still required, nitrogenous manures are as a rule requisite for both crops, and for the spring-sown one, barley, superphosphate also.

It has been seen, that under the influence of foreign competition (and possibly in part due to the greater attention paid to meat and milk production in later years), the area under the crop has been reduced. But there is no doubt that, in addition to the soils on which it is most appropriately grown in the ordinary course of rotation, barley may be grown, both in full quantity per acre, and of good quality, in succession to wheat, on the heavier soils, when the land is clean enough for a second corn crop.

G. H. HARMER, PRINTER, "STANDARD" OFFICE, CIRENCESTER.

Extrait des Archives des sciences physiques et naturelles.
Novembre 1886, troisième période, t. XVI, p. 421.

REMARQUES SUR LA RELATION

QUI EXISTE

ENTRE LES SOMMES DE TEMPÉRATURE ET LA PRODUCTION AGRICOLE[1]

PAR

M. le Prof. J.-H. GILBERT
de la Société Royale de Londres et correspondant de l'Institut.

Lorsque je reçus l'invitation de prendre part à la soixante-neuvième session annuelle de la Société helvétique des sciences naturelles, le seul motif qui aurait pu me faire hésiter à accepter cette proposition était la crainte que mes nombreuses occupations ne me permissent pas de préparer une communication digne de l'honneur que cette Société me faisait en m'invitant. Cependant il me vint à l'idée qu'il ne serait pas mal à propos de profiter de l'occasion pour contribuer, en quelque chose, à la discussion d'un sujet qui a déjà été traité, avec une grande lucidité et d'une manière si instructive, par un savant Suisse que je m'ho-

[1] Ce mémoire a été lu par l'auteur à la Section de botanique de la Société helvétique à Genève en août 1886, et nous le traduisons ici textuellement, avec son autorisation.

nore de voir ici en la personne de M. Alphonse de Candolle. Le sujet auquel je fais allusion est l'étude des données météorologiques dans leurs rapports avec l'accroissement des végétaux.

C'est là, sans doute, une question fort étendue, mais je dois, en l'abordant, prévenir que dans les observations sur lesquelles je désire fixer l'attention de la Société, je me bornerai à la considération des sommes de chaleur nécessaires à l'accroissement et à la maturation de certaines cultures, spécialement du blé.

Il y a bien des années que Boussingault s'est occupé de ce sujet. Il essaya alors de calculer les capacités relatives de diverses contrées pour la production des céréales. M. de Candolle a aussi discuté, d'une manière approfondie, l'influence de plusieurs éléments météorologiques sur la croissance des plantes et abordé, en détail, les difficultés que l'on rencontre dans l'application des données météorologiques à l'étude des phénomènes de la vie végétale. Il a, en même temps, indiqué les meilleures méthodes d'observation et de calcul à employer dans ce genre de recherches.

A propos des résultats que je vais exposer, je dois rappeler que, depuis l'année 1878, le bureau météorologique de Londres, sous la direction de M. R.-H. Scott, fournit chaque semaine un bulletin rédigé spécialement à l'usage des personnes qui s'occupent d'agriculture ou de questions se rapportant à la salubrité publique.

Au mois de décembre 1881, le bureau publia une circulaire demandant aux agriculteurs quelles statistiques météorologiques leur seraient les plus utiles et sous quelle forme il conviendrait de les leur présenter. En réponse à cet appel nous formulâmes, sir J.-B. Lawes et moi, quel-

ques propositions et, entre autres, celle que les sommes de température, au-dessus d'un point fixe convenablement choisi, devraient être calculées et notées en diverses saisons et en divers lieux afin que l'on pût voir jusqu'à quel point ces données pourraient être utilisées dans l'étude de la relation entre la température et la production agricole. Nous fîmes, de plus, remarquer qu'il était nécessaire d'enregistrer aussi les sommes d'heures d'insolation et de pluie.

Si les données relatives à la température et aux heures d'insolation semblent être les seuls moyens à notre portée pour apprécier l'efficacité des rayons solaires, il n'en est pas moins probable qu'il serait important de considérer la qualité aussi bien que la quantité de la chaleur reçue par les plantes surtout, eu égard aux diverses périodes de l'année.

Nous avions déjà, nous-même, tenté précédemment d'évaluer l'effet de la température sur le blé, pendant quelques années d'expériences régulières faites sur les cultures de Rothamsted. Comme nous ne disposions alors que des moyennes publiées tous les mois à Greenwich, nous avions pris alternativement le 1er mars et le 1er avril de chaque année comme marquant le début de la croissance des plantes hors de terre et la date de la moisson à Rothamsted comme marquant la fin de la période de végétation. Nous retranchions ensuite 43° F. (soit 6°,11 C.) de la température moyenne du mois ; puis en multipliant la différence ainsi obtenue par le nombre de jours de végétation et en ajoutant enfin ces produits pour toute la période considérée, nous arrivions à un chiffre qui était censé représenter la somme des degrés de température efficace.

Nous reconnûmes cependant que les moyennes men-

suelles étaient tout à fait insuffisantes et nous nous décidâmes, en conséquence, à rassembler les moyennes quotidiennes pour un grand nombre d'années afin d'arriver à des évaluations plus exactes.

J'attirerai, tout à l'heure, l'attention sur les résultats obtenus en se servant soit de la température moyenne de chaque jour, soit de la moyenne mensuelle, mais je dois auparavant exposer en quelques mots les principes qui ont conduit à des évaluations plus exactes pour ces dernières années ainsi que les méthodes employées dans leur calcul.

En vue de fournir, comme nous l'avions suggéré, l'indication des sommes de température, le général Strachey, président du bureau météorologique, a établi une formule donnant la vraie valeur de la moyenne quotidienne, déduite des températures notées d'heure en heure, et il a comparé les résultats ainsi obtenus à ceux de l'emploi de la méthode ordinaire qui consiste à prendre chaque jour la moyenne entre le maximum et le minimum de température. Il a trouvé qu'il n'y avait presque point de différence entre ces résultats pour l'hiver, mais un peu plus en été, c'est-à-dire pendant la saison où ils trouvent leur principale application à l'étude de la végétation. Pour une certaine période de l'année 1881, par exemple, la formule du général Strachey fixait la somme des températures à 1623° F. (soit 902° C.), tandis qu'en se servant de la méthode ordinaire on obtenait 1664° F. (924° C.). L'année suivante, la formule donna 1525° F. (847° C.) contre 1573° F. (874° C.) chiffre obtenu par l'autre méthode.

Depuis l'année 1884 le bureau météorologique publie, à l'usage des agriculteurs, les sommes de températures quotidiennes au-dessous et au-dessus de 42° F. pour

chaque semaine, ainsi que les sommes enregistrées depuis le mois de janvier. Ajoutons que les mêmes sommes ont été calculées rétrospectivement jusqu'à l'année 1878 inclusivement.

Ce sont ces documents que nous avons ensuite utilisés dans nos propres recherches. A cet effet, nous avons calculé la somme des degrés en excès au-dessus de 42° F., à partir de certaines dates arbitraires telles que le 1er janvier, le 1er mars, 1er avril et jusqu'à la coupe de nos blés d'expérience à Rothamsted. En même temps nous avons évalué les sommes à partir de la première semaine d'excès sensiblement continu et aussi à partir de chaque renouvellement d'excès succédant à une insuffisance temporaire de température.

Le tableau ci-après donne, en degrés de l'échelle centigrade :

1° Pour une période de 27 années (1852 à 1878) le maximum et le minimum des sommes de température au-dessus de 5°,55, enregistrées à Greenwich et calculées respectivement des 1er février, 1er mars, 1er avril de chaque année jusqu'à l'époque des récoltes du blé à Rothamsted, en utilisant seulement les moyennes mensuelles.

2° Pour une période de 6 ans (1871-1876), le maximum, le minimum et la moyenne au-dessus de 5°,55, depuis les mêmes époques jusqu'à la moisson, mais en calculant d'après les moyennes quotidiennes de Greenwich.

3° Les mêmes maxima et minima, ainsi que leurs moyennes, de 1878 à 1885, toujours en partant des mêmes dates, et enfin les excès de température des mêmes époques initiales jusqu'à la récolte, estimées à partir du commencement du premier excès sensiblement continu et aussi à partir de chaque renouvellement d'excès après une insuffisance temporaire ; ces calculs étant, d'ailleurs,

basés sur les tableaux des sommes d'excès hebdomadaires calculés par la méthode du général Strachey [1] et publiés chaque semaine par les soins du bureau météorologique.

Somme des excès des moyennes quotidiennes au-dessus de 5,55 C. (=42° F.) à partir de certaines dates fixes ou depuis le commencement de la croissance hors de terre jusqu'à la récolte.

	Depuis le 1er Janvier	Depuis le 1er Février	Depuis le 1er Mars	Depuis le 1er Avril	Depuis le début des excès hebdomadaires continus	Depuis chaque retour d'excès hebd. après insuffisance
D'après la moyenne mensuelle à Greenwich.						
27 années 1852 à 1878 — Maxim..	1213	1213	1213	1213		
27 années 1852 à 1878 — Minim..	1036	1025	1025	1004		
27 années 1852 à 1878 — Moyenne.	1124	1121	1113	1100		
D'après les moyennes quotidiennes de Greenwich.						
Six années 1871-76 — Maxim..	1269	1255	1212	1179		
Six années 1871-76 — Minim..	1144	1120	1103	1042		
Six années 1871-76 — Moyenne.	1216	1190	1166	1116		
D'après les évaluations d'excès quotidiens calculés par le bureau météorologique [1].						
1878	1111	1083	1036	982	1111	1083
1879	1106	1106	1090	1045	1106	1089
1880	1108	1098	1055	969	1098	1098
1881	1009	1008	1002	944	1008	1002
1882	1121	1093	1031	946	1126	1092
1883	994	968	925	904	984	914
1884	1026	976	937	867	1026	937
1885	986	973	930	889	986	942
Maximum	1121	1106	1090	1045	1126	1098
Minimum	986	968	925	867	984	914
Moyenne	1058	1038	1003	943	1056	1020

[1] Moyenne pour les comtés de l'est et du centre de l'Angleterre.

[1] Dans la conférence de météorologie à l'Exposition internationale d'hygiène tenue à Londres en 1884, M. R.-H. Scott, F. R. S., a lu un travail sur les sommes de température. Au cours de la discussion qui s'en est suivie, le général Strachey a exposé en détail sa méthode de calcul, et le Dr Gilbert, qui présidait la séance, a aussi émis son avis sur le sujet.

1° Nous remarquons en premier lieu, qu'en prenant les résultats moyens pour 27 années, d'après les moyennes mensuelles seulement, la différence entre les sommes est très petite, que nous les calculions à partir du 1er janvier, du 1er février, du 1er mars ou du 1er avril.

En effet, la somme moyenne des degrés d'excès quotidiens, au-dessus de 5,55, jusqu'à la date de la récolte est de 1124° à partir du 1er janvier, de 1121° à partir du 1er février, de 1113° à partir du 1er mars et enfin de 1100° à partir du 1er avril. Il est évident que la seule explication de cette uniformité, dans notre localité et sous notre climat, est qu'il y a peu d'excès de température, au-dessus de 5,55°, avant le 1er avril. Or les tableaux météorologiques montrent précisément que dans presque aucune des 27 années il n'y a eu d'excès dans le mois de mars, encore moins en février et seulement dans deux années un excès quelconque en janvier.

2° Dans les 6 années, calculées d'après les moyennes quotidiennes de Greenwich, les différences sont plus grandes. Ainsi les sommes des degrés d'excès quotidiens sont de 1216° depuis le 1er janvier jusqu'à la récolte, de 1190° depuis le 1er février, de 1166° depuis le 1er mars et enfin de 1116° depuis le 1er avril.

3° Si maintenant nous envisageons les résultats obtenus par la méthode plus exacte, mais pour huit années seulement, nous constatons à la fois et des chiffres plus faibles et de plus grandes différences selon la date adoptée comme point de départ. Les moyennes pour les quatre périodes étant 1058, 1038, 1003 et 943. Mais, en sus des évaluations calculées depuis des dates arbitraires, nous avons aussi, dans cette série, les sommes qu'on obtient en partant, chaque année, du commencement d'un excès

sensiblement continu d'une semaine à l'autre, ainsi que celles calculées chaque semaine, depuis le retour d'un excès continu après une période d'insuffisance.

Les moyennes valeurs pendant ces 8 années, pour ces deux périodes, sont 1056° et 1020° qui se rapprochent davantage de celles obtenues pour les périodes s'étendant du 1er janvier ou 1er février jusqu'à la récolte que de celles calculées depuis le 1er mars ou le 1er avril.

Ainsi, depuis la levée des graines jusqu'à la récolte, nous constatons un excès de la moyenne quotidienne au-dessus de 5,55°, d'à peu près 1120° pendant les vingt-sept années, d'à peu près 1200° pendant les six années et enfin d'environ 1060° pendant la période de huit années.

On sait que Boussingault a évalué ces sommes pour le blé d'hiver dans quatre et pour le blé de printemps dans six contrées, très éloignées les unes des autres et présentant entre elles de grandes différences tant sous le rapport de la durée de croissance des plantes que sous celui de la température moyenne. En outre, il tenait compte de tous les degrés au-dessus de 0°. Si, après avoir réduit ses résultats de manière qu'ils ne correspondent plus qu'aux sommes des excès au-dessus de 5,55°, nous en retranchons ensuite le produit de cette température initiale par le nombre de jours indiqué, nous obtenons pour le blé d'hiver le chiffre 1316° et 1528° pour celui de printemps. Par conséquent, il est clair que les valeurs de Boussingault sont plus grandes que les nôtres.

Mais si nous nous rappelons que ses calculs sont basés seulement sur des évaluations générales de durées moyennes de croissance pour différents pays en prenant comme point de départ pour le blé d'hiver la cessation de la gelée, et pour le blé de printemps le temps écoulé entre les se-

mailles et la récolte, et enfin si nous réfléchissons qu'il adoptait une température moyenne pour toute la durée de la croissance, l'exactitude de ses résultats paraîtra plus remarquable que leurs différences d'avec les nôtres.

Hervé-Mangon, qui expérimentait au nord-est de la France, a trouvé une moyenne de 1924° pour le blé, pendant une période de huit années, en calculant depuis le 1er mars jusqu'à la récolte. Il ne tenait pas compte des températures au-dessus de 6°, quand la moyenne n'atteignait pas cette température, mais quand elle l'atteignait, il notait tous les degrés. Si nous réduisons ces chiffres comme nous l'avons fait tout à l'heure pour ceux de Boussingault, de manière à ne tenir compte que des degrés supérieurs à 5,55°, sa moyenne sera de 1030°, beaucoup plus rapprochée, par conséquent, de la nôtre que de celle de Boussingault.

M. E. Risler a fait aussi des observations de ce genre pendant dix années, dans sa propriété située aux environs de Nyon en Suisse. La moyenne de ses résultats est de 2134°, des semailles jusqu'à la récolte, en enregistrant tous les degrés supérieurs à 0°, lorsque la moyenne de température dépassait 6°. Si nous défalquons de cette somme le produit de 5,55° par 165 jours de durée moyenne de croissance, nous obtenons 1218°, valeur que nous pouvons comparer à celles de Boussingault et de Hervé-Mangon, citées plus haut.

Jusqu'ici nous ne nous sommes occupé que du blé, mais Boussingault ainsi qu'Hervé-Mangon ont fait des expériences sur l'orge et Boussingault a aussi expérimenté sur le maïs et quelques autres cultures. Pour l'orge semée au printemps, en prenant la moyenne d'expériences faites dans quatre localités éloignées les unes des au-

tres, des semailles à la moisson, Boussingault obtient une somme de 1772° au-dessus de 0°, soit de 1114° au-dessus de 5,55°.

Pour l'orge semée en hiver, en calculant depuis la cessation de la gelée, la moyenne de ses trois évaluations est de 1798° au-dessus de 0°, soit de 1152° au-dessus de 5,55°.

La moyenne des évaluations d'Hervé-Mangon pour six années consécutives (1871-1878) d'expériences faites sur l'orge, est de 1810° au-dessus de 0°, 1105° au-dessus de 5,55°. Nous voyons, d'après ces chiffres, que les évaluations de Boussingault et d'Hervé-Mangon se ressemblent beaucoup en ce qui concerne l'orge et que, relativement au blé, elles se rapprochent fort de nos propres résultats.

Le maïs, c'est un fait bien connu, exige une température plus élevée et surtout une plus longue durée de cette température que le blé. Or les moyennes des évaluations de Boussingault relatives à sept localités distantes, donnent pour cette plante, une somme de 2701° au-dessus de 0°, c'est-à-dire de 1953° au-dessus de 5,55°, somme beaucoup plus élevée qu'aucune de celles obtenues pour le blé et l'orge.

Les différents résultats obtenus pour le blé ne permettent pas de douter qu'il n'y ait un grand fond de vérité à conclure qu'il règne une uniformité approximative dans les sommes de chaleur nécessaires pour amener les plantes de leurs premiers débuts de végétation à leur maturation finale.

Il semblerait aussi, d'après cela, que les sommes totales indispensables à l'orge sont presque les mêmes que celles qu'exige le blé, tandis que celles nécessaires au maïs sont beaucoup plus élevées que pour l'orge et le blé.

Mais tandis que les moyennes obtenues pour le blé cultivé sous des conditions si diverses, sont généralement concordantes, il n'est nullement certain que la température de 5,55° doive être adoptée comme origine, ainsi que nous l'avons fait dans nos calculs basés sur les évaluations des sommes de température au-dessus de ce point, d'après les données du bureau météorologique.

On peut aussi se demander si dans le cas où ces données indiquent des températures plus élevées que l'origine adoptée, il serait préférable d'englober dans les sommes seulement tous les degrés au-dessus de ce point initial, ou s'il convient d'y faire rentrer tous ceux qui surpassent 0° C.

A la vérité, les résultats obtenus fournissent plutôt des matériaux d'étude qu'une solution complète de la question du degré à adopter comme température initiale.

D'après Boussingault la température ~~la plus basse~~ à laquelle les diverses plantes puissent végéter, varie de 3° ou 4° à 40° ou 5[illegible]°, et l'on doit à M. de Candolle des tableaux démontrant les grandes différences qui existent entre les sommes nécessaires à l'accroissement selon que l'on part de 1°, 2°, 3°, etc., comme température initiale. En fait, il paraît probable que le blé, ainsi que l'orge, végètent au-dessous de l'origine adoptée dans nos calculs soit au-dessous de + 5,55°.

Nous ne nous sommes occupé encore que des résultats moyens indiqués dans notre tableau. Mais les chiffres qu'il contient nous montrent aussi qu'il y a une grande différence entre les sommes maxima et minima obtenues en différentes saisons.

Cette différence peut résulter en partie de ce que nous n'avons pas adopté pour le début et l'arrêt de végétation

des plantes, des périodes également applicables aux diverses saisons. Une autre cause réside peut-être dans l'exclusion que nous avons faite de tous les degrés au-dessous de 5,55°. Mais une portion de cette différence est certainement due à ce que le même excès moyen au-dessus d'une origine fixe quelconque peut résulter de températures maxima et minima très différentes ; les minima arrêtant la croissance des plantes dans quelques cas, mais pas dans d'autres et les maxima pouvant être supérieurs à la température la plus efficace.

En outre, une même température doit produire des résultats fort divers et donner lieu à des effets d'assimilation très différents, sur une même surface et en un temps donné, selon les phases de la croissance et l'étendue de la surface assimilatrice des plantes que l'on étudie. Enfin l'humidité ambiante doit aussi influencer les résultats.

On doit donc s'attendre à ce qu'il se produise, d'une année à l'autre, quelques variations dans les sommes de température et les chiffres de chaque année demandent eux-mêmes à être comparés avec les conditions relatives aux saisons envisagées sous d'autres rapports, ainsi qu'avec celles inhérentes aux plantes.

Il est manifeste que des saisons différentes différeront presque indéfiniment aux diverses phases successives de leur durée et qu'à chacune de ces variations climatériques en correspondra une autre dans le développement de la plante elle-même, selon qu'il tendra à une exubérance de végétation ou à la maturation.

C'est pourquoi un système de statistiques détaillées faites concurremment avec de soigneuses observations agricoles répétées périodiquement en grande culture, peut seul donner une idée vraiment claire du rapport entre les

caractères incessamment variables des saisons et les caractères également changeants de la croissance des plantes et de la production.

C'est en effet la distribution des différents facteurs dont la saison se compose, leurs adaptations mutuelles et leur adaptation à l'état de développement, qui influent sur les tendances et les résultats de la croissance de la plante. Il arrive, en outre, parfois que des conditions accidentelles, non indiquées par les tables météorologiques, influent sur la récolte d'une manière très remarquable.

La cause de cette influence passera inaperçue à moins que l'on ne fasse des observations soigneuses et si l'on ne tient compte des phases et des tendances de la croissance de la récolte elle-même.

A ce sujet il sera utile de comparer l'influence de la durée d'insolation à celle des sommes de température, sur les progrès et l'intensité de la croissance végétale.

Dans notre pays et sous notre climat, qui ne sont pas caractérisés par l'abondance de jours de soleil, la période de l'année présentant le plus grand nombre de jours d'insolation précède de beaucoup celle qui offre la plus haute moyenne de température et pendant laquelle a lieu la plus grande accumulation de carbone sur une surface donnée. Cette accumulation, en effet, s'effectue surtout pendant la période de la plus haute moyenne de température. Ainsi, d'après les données du bureau météorologique pour les six dernières années (1880-1885), la semaine présentant le plus grand nombre de jours d'insolation, dans les deux districts confinant à Rothamsted, tombe six fois en mai et trois fois en juillet ; tandis que, dans les deux mêmes districts la semaine de la plus haute moyenne de température se trouve six fois en juillet, qua-

tre fois en août et deux fois au commencement de septembre. Cela revient à dire que la période de l'année qui contient le plus grand nombre de jours d'insolation a lieu, en général, longtemps avant le jour le plus long de l'année ou, en d'autres termes, avant l'époque qui pourrait offrir la plus grande durée possible d'insolation, tandis que la période de la plus haute température a ordinairement lieu plusieurs semaines plus tard.

A propos de ces périodes il est intéressant de remarquer que, dans des expériences faites il y a quelques années à Rothamsted, on trouva que, pour une récolte de blé, la quantité de carbone avait plus que doublé en cinq semaines depuis le 21 juin ; c'est-à-dire que la plus forte accumulation de carbone, pour une superficie donnée, avait lieu après la période de la plus longue durée d'insolation et se produisait aux approches de la période de la plus haute température.

Ce qui précède est tout à fait conforme aux opinions en cours concernant les rayons qui sont les plus efficaces pour l'assimilation du carbone par les plantes. Mais il faut pourtant se rappeler que la période de plus rapide accumulation de carbone par le blé coïncide aussi avec celle du plus rapide accroissement quotidien de sa surface verte ; de sorte qu'il existe à ce moment des conditions favorables à l'accumulation, inhérentes à la plante elle-même.

D'après les résultats que nous venons de faire connaître, il devient évident que s'il ne peut y avoir aucun doute que des plantes différentes exigent des sommes de températures différentes pour atteindre leur complet développement, il n'en existe pas moins une uniformité générale quant à la somme relative à une même espèce

cultivée sous des conditions très diverses de variation et de durée de la température. Mais il est tout aussi évident que des observations beaucoup plus minutieuses que celles faites jusqu'à ce jour, sont nécessaires pour arriver à une appréciation exacte des besoins d'espèces différentes.

A la vérité, dans le cas du blé, nous manquons encore d'observations suffisantes pour trancher la question du zéro ou température initiale qu'il convient d'adopter. Il y aurait même à discuter la phase de son développement qui correspond à la terminaison de son assimilation ou à sa maturité. Il est, toutefois, manifeste que les résultats obtenus par divers observateurs en diverses contrées et avec différentes espèces suffisent à indiquer les limites des aires dans lesquelles certaines récoltes peuvent ou ne peuvent pas être avantageusement cultivées.

Ce n'est néanmoins pas la même chose d'obtenir des données suffisamment exactes pour la discussion des questions de ce genre que d'arriver à discerner entre une saison et une autre relativement à une même localité ou entre différentes localités du même pays, quant à leur adaptation plus ou moins satisfaisante à la maturation plus ou moins précoce de chaque récolte. Sous ce dernier point de vue je ferai observer que, d'après les calculs basés sur les tables de sommes de température publiées par le bureau météorologique, il y a pour une période de huit années un moyen écart de 33 jours entre les époques auxquelles la somme considérée comme nécessaire à la maturation du blé dans notre localité est atteinte dans le plus précoce et dans le plus tardif des cinq districts classés comme favorables à cette culture. D'autre part, dans cinq districts classés comme favorables au

fourrage, la même somme serait atteinte à des époques réparties sur une durée de 24 jours seulement. Le plus retardé de ces districts ne le serait d'ailleurs pas, en moyenne, davantage que le plus tardif des districts à blé. En fait, dans les districts fourragers, c'est la grande quantité de pluie plutôt que le manque de chaleur qui décide du résultat.

Nous trouvons donc dans cet exemple de l'application pratique des sommes de température, une preuve directe de l'influence modificatrice exercée par d'autres facteurs météorologiques. Il en ressort la nécessité d'avoir recours à une observation soigneuse et détaillée de tous ces facteurs et de leur adaptation au caractère ainsi qu'à la phase de développement de la plante elle-même.

10

THE HOME PRODUCE, IMPORTS, CONSUMPTION,

AND

PRICE OF WHEAT IN THE UNITED KINGDOM.

(*Reprinted from "The Field," February 12th*, 1887.)

THE SUBJOINED TABLE gives particulars of the home produce, imports, consumption, and price of wheat, in the United Kingdom, for thirty-four harvest years, 1852-3 to 1885-6 inclusive. The table, in fact, brings up to date records on the points in question which we gave in 1868 up to that date, in the Journal of the Royal Agricultural Society of England, and in 1880 up to that date, both in the Journal of the Statistical Society and in that of the Agricultural Journal above referred to.

It is obvious that the main elements of the question are—the area under wheat, the average yield per acre, the imports, the population, and the average consumption per head per annum.

So far as the area, the imports, and the population are concerned, we of course rely on official returns; which, especially in the matter of the area under the crop, have been very much more trustworthy in the later than in the earlier years of our estimates. The sources and the character of the data available on all the

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1887.

points have, however, been discussed in the various papers above alluded to, in more detail in the first, and in the later ones so far as was necessary for confirmation or amendment.

The results for which we have had to rely mainly on our own judgment, and for which therefore we are, more than for the rest, ourselves responsible, are the estimates of the average yield of wheat per acre in the United Kingdom each year, and of the average consumption per head per annum of the population. Naturally, too, it is just these points of estimate rather than of record which have the most frequently been called in question. It would be impossible to give an adequate explanation or vindication of our modes of estimate within the limits of a few short paragraphs. For this we must refer to our original papers above quoted; but a few observations may aid a judgment on the subject.

In 1863, and each year since, there has been published soon after harvest, in *The Times* and other journals, an estimate of the average yield of wheat per acre in the United Kingdom. This estimate is founded on the yield of certain plots in the experimental field at Rothamsted, in which wheat has now been grown every year from 1844 inclusive, up to the present time. In our paper in 1868, the estimates are carried back to 1852, and they are given for seventeen years, 1852 to 1868 inclusive. The method of obtaining them is also fully described and discussed. The mean of the produce of certain very differently manured plots is taken, and the resulting figure is frequently adopted without modification, but sometimes with more or less of modification, according to the peculiarities of the season; that is, whether it is more favourable for the poorer or the more fertile, the drier or the wetter districts, and so on.

The estimates of average yield per acre recorded in the second column of the table are those which have been arrived at as above described, and it is these which have from time to time been called in question. It is not proposed to discuss the correctness of the estimates for individual years. It is obvious, however, that upon

their general correctness depends the correctness of the estimates of the gross home produce, and of the amount available for consumption from that source, whilst it is this amount, added to the net imports, that shows the actual consumption over series of years. It will be well, therefore, to consider how far the estimates of average yield per acre, and those of consumption per head of the population, mutually confirm one another.

In the annual letters published soon after harvest, the plan has been to estimate (1) the average yield per acre over the United Kingdom; (2) the consumption per head, and from it the total requirement for the succeeding harvest-year; (3) the amount required accordingly from stocks and imports.

Now it is obvious that any material error in the estimate of the average yield per acre, from which is reckoned the amount available for consumption from home produce, must influence the estimates of the requirement from imports, &c.; and as the imports are afterwards accurately known, such error must manifest itself when the results are considered for a sufficient series of years to eliminate the disturbing influence of stocks on hand. Then again, as the amounts estimated to be available from home produce, added to those imported, give the total consumption, the results so arrived at must, over a series of years, afford a very effective control of the estimates of average consumption per head of the population, upon which the estimate of the requirement from stocks and imports is annually based. This subject was fully considered in our 1880 papers, and we must refer to them for details; but it may be well to give some illustrations on the point.

Commencing with the harvest-year 1852-3, we estimated the average consumption per head per annum at 5·1 bushels over the first eight years, and 5·5 bushels each year afterwards, until, in 1880, we reconsidered the subject. We then calculated the average home produce per acre from the total consumption according to the above estimates of consumption per head, deducting from this the imports, adding 2¼ bushels per acre for

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1887.

seed, and dividing by the number of acres; and we compared the estimates of home produce per acre so arrived at with those given each year soon after harvest. The following was the result:

Periods for which Averages are Calculated.	Average Produce per Acre.		
	According to Consumption and Imports.	According to annually adopted Estimates.	Annual Estimates + or − Calculated.
	Bushels.	Bushels.	Bushels.
8 years, 1852-59	28¼	28	− 0⅛
8 years, 1860-67	28⅛	28⅛	0
8 years, 1868-75	26½	26⅞	+ 0⅜
3 years, 1876-78	25⅞	27⅛	+ 1¼
27 years, 1852-78	27⅛	27⅛	+ 0⅛

It will be seen that over the two later periods, including eleven years, the estimates annually published soon after harvest are higher than those founded on the estimated consumption and the actual imports. It is obvious that either the annual estimates are too high, or the estimates of total consumption over those two periods are too low. On full consideration of the details, we concluded that the estimates of the total consumption—that is, the amount consumed as human food, together with that consumed by stock—were more probably too low than that the estimates of produce per acre were too high. Considering, too, not only the great difficulty of forming anything like a trustworthy estimate of the amount consumed other than as human food, but also the fact that it bears, at any rate on the average, a very small proportion to that so consumed, we decided that there was probably less error in fixing the estimate of consumption per head so as to include the very small average consumption in other ways, than in attempting to estimate the consumption by stock, &c., separately. We accordingly adopted the rate of consumption as follows: First eight years, 5·1 bushels per head; second eight years, 5·5 bushels; third eight years, 5·6 bushels; fourth eight years, and since, 5·65 bushels. Adopting these estimates of total consumption, but expressed in

quantities consumed per head of the population, the average produce per acre over the several periods would be:

Periods for which Averages are Calculated.	Average Produce per Acre.	
	According to increased Consumption and Imports.	According to annually adopted Estimates.
	Bushels.	Bushels.
8 years, 1852-3 to 1859-60	28½	28
8 years, 1860-1 to 1867-8	28⅝	28⅝
8 years, 1868-9 to 1875-6	27	26¾
8 years, 1876-7 to 1883-4	24⅝	25
32 years, 1852-3 to 1883-4	27⅛	27⅛

Thus, if we adopt the rate of consumption over the successive periods as given above, the estimates of average yield per acre, reckoned, on the one hand according to consumption and imports, and on the other as given each year soon after harvest, agree very closely for each period of eight years, and they are identical for the total period of thirty-two years; the result being for the whole period, according to both methods, 27⅛ bushels per acre per annum.

With regard to our estimates of consumption per head, it may be stated that they were originally founded, partly on the calculation of numerous dietaries, and partly on the estimates of home produce and the recorded amounts of the imports. Owing to defective data, we considered that our estimate of 5·1 bushels per head over the first eight years was probably somewhat too low. Again, although we do suppose that there was an increased consumption over the second period compared with the first, and that the rate of increase was greater then than afterwards, we of course do not suppose that there was the sudden rise from 5·1 to 5·5 bushels at the end of the first period. The reasons for raising the estimate after the first two periods have already been explained; and it has also been explained why we did not make a separate estimate for the amounts consumed by stock, or in other ways.

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1887.

On this point it may be further observed, that the consumption in manufactures of any kind is very small; whilst, as a rule, it is only the offal wheat that is given to stock, and as this is excluded in our estimate of yield per acre, such consumption by stock does not vitiate our estimates of consumption per head. When, however, the price is low, more offal will be dressed out, and so the sample for sale improved. Doubtless, too, the very low prices in recent years have led to the consumption at home of some wheat that would otherwise have gone to market; but there is no reason to suppose that this has taken place to such an extent as materially to affect our estimates. Time will, however, show whether or not this is the case.

It has, indeed, recently been alleged—first, that whilst we adopt 5·65 bushels as the consumption per head, other authorities take it at only 5½ bushels; and, secondly, that our estimates take no account of the consumption by stock. This, Mr E. King Fordham estimated at probably 2,000,000 quarters over the last harvest year, and Mr W. J. Harris at two bushels per acre per annum over the last three years.

Now, as to the rate of consumption per head, we are not aware of any estimate, founded on independent data, since our own in 1868, amended in 1880, until, in *The Economist* of Jan. 29 (1887), Mr W. J. Harris makes such an estimate. He divides the fifteen civil years, 1871 to 1885, into five triennial periods, and, taking the estimate of the home produce per acre of each of those years as given in Dornbusch's lists, and the net imports, he reckons that the consumption per head per annum was, over those five periods, 343, 347, 349, 354, and 337 lb. respectively, which correspond to 5·62, 5·69, 5·72, 5·80, and 5·52 bushels per head per annum; or, for the whole period of fifteen years, to 5·67 bushels. This estimate agrees, therefore, almost absolutely with our own. But, over the first four of the five triennial periods, when Mr Harris makes no allowance for consumption by stock, his estimates correspond to 5·71 bushels, or rather higher than our own estimate of 5·65 for the total consumption. It is to be observed, too, that

it is only by assuming an extra consumption by stock at the rate of 2 bushels per acre per annum over the last triennial period, and deducting this from the available home produce, that Mr Harris shows a lower consumption per head over that period. That his estimates show on the average a somewhat higher rate of consumption per head than ours, depends on the fact that, according to the figures in Dornbusch's list, the average produce per acre per annum is, over the fifteen years, seven-eighths of a bushel higher than according to our own estimates.

It is to be observed that the principle of Mr Harris's calculations is the same as that of our own for the later periods. In both cases the data relied upon are, estimates of home produce and the returns of imports. The only difference is that Mr Harris calculates for civil years, and adopts Dornbusch's estimates of home produce per acre, whilst we calculate for harvest years, and take our own estimates of average produce per acre. As the two sets of results agree so closely, they obviously mutually confirm one another.

It may be taken for granted that the consumption by stock was larger than usual during the recent years of low prices; and the amount of such extra consumption assumed by Mr Harris would correspond to about 640,000qrs. per annum, and to about 0·14, or one-seventh of a bushel, per head of the population. If however, as supposed probable by Mr Fordham, we were to assume that there was an extra consumption by stock of 2,000,000qrs. in the last harvest year, this would, with a population of 36,600,000, as it was in round numbers in 1885-6, affect the estimate of actual consumption per head of the population by 0·44 or about two-fifths of a bushel; or, on the other hand, an error of 2,000,000qrs. in the estimate of the total home produce would correspond to an error in the estimate of the yield per acre on the present area of about $6\frac{3}{4}$ bushels.

Further, supposing that the estimates of home produce, such as are given weekly in *The Economist*, and are founded on the market sales upon which the *Gazette* price is fixed, are relatively if not

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1887.

absolutely correct, we should expect that during a period of excessive consumption by stock they would show lower amounts, compared with our own estimates of home produce, than at other times. But the result is exactly the contrary. For example, whilst during the harvest-years 1880-1 and 1881-2 the estimates according to sales were below those of Rothamsted, in the four subsequent years to 1885-6 they exceeded those of Rothamsted.

In conclusion, we would remark that whilst 30 bushels per acre per annum is frequently assumed to be the average yield of the United Kingdom, our own estimate was, until recent years, 28½ bushels; but the series of bad seasons has reduced the average, over the thirty-two years to 1883 inclusive, to 27 bushels. We nevertheless still adopt 28 bushels as the normal average yield. If, however, our estimate of consumption is, as alleged, too high, the average yield per acre would be lower, not higher, than our figures show. If, on the other hand, it were established that there is a large consumption by stock or otherwise, over and above our estimate of total consumption, it is obvious that our estimates of average yield per acre are, so far, too low.

THIRTY-FOUR HARVEST-YEARS, 1852—3 TO 1885—6.

on- .	Value of Wheat (*) estimated to be consumed (at average "Gazette" price).		Per cent. of total available.		Harvest years. September 1 to August 31.
d.	Total.	Per Head.	From Home Produce.	From Imports.	
	£	s. d.			
472	39,095,914	28 5	63·9	36·1	1852—3
553	64,194,918	46 6	60·5	39·5	1853—4
475	62,029,742	44 8	84·6	15·4	1854—5
971	65,847,949	47 2	79·6	20·4	1855—6
444	53,871,810	38 4	76·0	24·0	1856—7
385	43,032,661	30 5	73·6	26·4	1857—8
404	39,701,015	27 10	76·9	23·1	1858—9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1887.

ON THE

PRESENT POSITION OF THE QUESTION

OF THE

SOURCES OF THE NITROGEN OF VEGETATION,

WITH SOME

NEW RESULTS, AND PRELIMINARY NOTICE OF NEW LINES OF INVESTIGATION.

BY

SIR J. B. LAWES, BART., LL.D., F.R.S.,

AND

PROF. J. H. GILBERT, LL.D., F.R.S.

PRELIMINARY NOTICE.

LONDON:
HARRISON AND SONS, ST. MARTIN'S LANE,
Printers in Ordinary to Her Majesty.

1887.

[*From the* PROCEEDINGS OF THE ROYAL SOCIETY, Vol. 43.]

"On the present Position of the Question of the Sources of the Nitrogen of Vegetation, with some new Results, and preliminary Notice of new Lines of Investigation." By Sir J. B. LAWES, Bart., LL.D., F.R.S., and J. H. GILBERT, LL.D., F.R.S. Preliminary Notice.* Received and read June 16, 1887.

For many years past the question of the sources of the nitrogen of our crops has been the subject of much experimental enquiry both at Rothamsted and elsewhere. Until quite recently, the controversy has chiefly been as to whether plants directly assimilate the free nitrogen of the atmosphere; but, during the last few years, the discussion has assumed a somewhat different aspect. The question still is whether the free nitrogen of the air is an important source of the nitrogen of vegetation; but whilst few now adhere to the view that chlorophyllous plants directly assimilate free nitrogen, it is nevertheless assumed to be brought under contribution in various ways, coming into combination within the soil, under the influence of electricity, or of micro-organisms, or of other low forms which thus indirectly serve as an important source of the nitrogen of plants of a higher order. Several of the more important of the investigations in the lines here indicated seem to have been instigated by the assumption that natural compensation must be found for the losses of combined nitrogen which the soil sustains by the removal of crops, and for those which result from the liberation of nitrogen from its combinations under various circumstances.

We propose to summarise some of our own more recently published results bearing on various aspects of the subject, to put on record additional results, to give a preliminary notice of new lines of enquiry, and to discuss the evidence so adduced with reference to the results

* This Preliminary Notice was originally intended to have served as the Abstract of a fuller paper, and is so referred to in the account of the meeting of June 16 (vol. 42, p. 483).

and conclusions of others which have recently been put forward, as above alluded to.

In our earlier papers we had concluded that, excepting the small amount of combined nitrogen annually coming down in rain and the minor aqueous deposits from the atmosphere, the source of the nitrogen of our crops was, substantially, the stores within the soil and subsoil, whether derived from previous accumulations, or from recent supplies by manure.

More recently we have shown that the amount of nitrogen, as nitric acid in the soil, was much less after the growth of a crop than under comparable conditions without a crop. In the case of gramineous crops the evidence pointed to the conclusion that most, if not the whole, of their nitrogen was taken up as nitric acid. In the experiments with leguminous crops the evidence was in favour of the supposition that, in some cases, the whole of the nitrogen had been taken up as nitric acid, whilst in others that source seemed to be inadequate.

It was further shown that, under otherwise parallel conditions, there was much more nitrogen as nitric acid in soils and subsoils down to a depth of 108 inches where leguminous than where gramineous crops had for some time been grown. The indication was that nitrification had been more active under the influence of leguminous than of gramineous growth and crop residue. At the same time, comparing the amounts of nitrogen as nitric acid in the soil where the shallow rooting *Trifolium repens* had previously been grown, with those where the deeper rooting *Vicia sativa* had yielded fair crops, it was found that, at every depth of 9 inches down to a total depth of 108 inches, the Vicia soil contained much less nitric acid than the *Trifolium repens* soil; and it was concluded that much if not the whole, of the nitrogen of the Vicia crops had been taken up as nitric acid.

New results of the same kind, which related to experiments with *Trifolium repens* as a shallow rooting and meagrely yielding plant, to *Melilotus leucantha* as a deeper rooting and freer growing one, and to *Medicago sativa* as a still deeper rooting and still freer growing plant, very strikingly illustrated and confirmed the result of the exhaustion of the nitric acid of the subsoil by the strong, deep-rooting, and high nitrogen-yielding Leguminosæ. For example, at each of the twelve depths of the Medicago soil there remained very much less nitrogen as nitric acid than where very much less nitrogen had been removed in the *Trifolium repens* crops; there being on the average not one-twelfth as much in the lower ten depths of the Medicago soil as in the corresponding depths of the *Trifolium repens* soil. Still, the figures did not justify the conclusion that the whole of the large amount of nitrogen taken up by the

Medicago crops, could have had its source in nitric acid. It is obvious that much nitrification takes place near the surface, but as the surface-soil became even somewhat richer in nitrogen, it was clear that the surface-soil has not been the primary source of the large amounts of nitrogen taken up by the plants. That source must in fact be either the atmosphere, or the subsoil; and if the subsoil, and yet not wholly as nitric acid, the question arises in what other form of combination?

In another experiment, one leguminous crop, beans, had been grown for many years in succession, and finally yielded very small crops, containing less than 30 lbs. of nitrogen per acre. The land was then left fallow for several years; barley and clover were sown in 1883, and in that year, 1884, and 1885, about 300 lbs. of nitrogen per acre were removed, chiefly in the clover crops. This result was obtained where another leguminous crop had practically failed, where the surface-soil had become very poor in total nitrogen, where there existed a very small amount of ready-formed nitric acid to a considerable depth, and where the surface was unusually poor in nitrogenous crop residue for nitrification. Further, not only had this large amount of nitrogen been removed in the clover crops, but the surface-soil became determinably richer in nitrogen. Here again, then, the primary source of the nitrogen, of the crop could not have been the surface-soil itself. It must have been either the atmosphere, or the subsoil; and assuming it to be the subsoil, the question arises whether it was taken up as nitric acid, as ammonia, or as organic nitrogen?

The results adduced could leave no doubt that nitric acid was an important source of the nitrogen of the Leguminosæ. Indeed, existing experimental evidence relating to nitric acid carries us quantitatively further than any other line of explanation. But it is obviously quite inadequate to account for the facts of growth, either in the case of the *Medicago sativa* experiments, or in that of the clover on the bean-exhausted land.

Direct experiments were made to determine whether the nitrogen of the Rothamsted raw clay subsoils, from which it is assumed much nitrogen has been derived in some way, was susceptible of nitrification, provided the nitrifying organisms, and other necessary conditions, were present. It was found that the nitrogen of such subsoils, containing only about 0·04 or 0·05 per cent. of nitrogen, and not more than 6 or 8 parts of carbon to 1 part of nitrogen, was susceptible of nitrification. It was also found that nitrification was more active in leguminous than in gramineous crop subsoils. Obviously, however, the conditions of nitrification in which samples are exposed in the laboratory, are very different from those of the subsoil *in situ*.

Although the evidence is clear that the nitrogen of raw clay subsoils, which constitutes an enormous store of already combined nitrogen, is susceptible of nitrification, provided the organisms are present and the supply of oxygen is sufficient, the data at command do not indicate that these conditions could be adequately available in such cases as those of the very large accumulations of nitrogen by the *Medicago sativa* for a number of years in succession, or by the red clover on the bean-exhausted land.

The question arose—whether roots, by virtue of their acid sap, might not, either directly take up, or at any rate attack and liberate for further change, the otherwise insoluble organic nitrogen of the subsoil. Accordingly, in the autumn of 1885 specimens of the deep, strong, fleshy root of the *Medicago sativa* were collected and examined, when it was found that the sap was very strongly acid. The degree of acidity was determined, and attempts were made so to free the extract from nitrogenous bodies as to render it available for determining whether or not it would attack and take up the nitrogen of the raw clay subsoil. Hitherto, however, these attempts have been unsuccessful.

Also in the autumn of 1885, when this difficulty first arose, it was decided, in the mean time, to examine the action on soils and subsoils of various organic acids, in solutions of a degree of acidity either approximately the same as that of the lucerne root-juice, or having a known relation to it. The acids used were the malic, citric, tartaric, oxalic, acetic, and formic.

It was found that the weak organic acid solutions did take up some nitrogen from the raw clay subsoil, and more from the poor lucerne surface-soil. But when solutions of only approximately the acidity of the root-sap were agitated with an amount of soil which it was thought would be sufficient to yield so much nitrogen as to insure accurate determination, it was found that the acid frequently became neutralised by the bases of the soil, and that less nitrogen remained dissolved after a contact of twenty-four hours, or more, than after only one hour. The strength of the acid liquids was therefore increased, and the relation of soil to acid diminished. More nitrogen was then taken up, and more after the longer than the shorter period of contact. Still, on adding fresh acid solution to the already once extracted soil, a limit to the amount of nitrogen rendered soluble was soon reached.

Here again, the conditions of experiment in the laboratory are not comparable with those of the action of living roots on the soil, and the results obtained do not justify any very definite conclusions as to whether the action of the roots on the soil by virtue of their acid sap is quantitatively an important source of the nitrogen of plants having an extended development of roots, of which the sap is strongly acid.

Provided this were clearly established to be the case, the question would still remain, whether the complex nitrogenous body is merely rendered soluble, and taken up as such, as is probably the case with the fungi, or whether, after being attacked, it is subjected to further change before entering the plant?

In the autumn of 1885, Dr. G. Loges published the results of experiments in which he acted upon soils by pretty strong hydrochloric acid, and determined the amount of nitrogen taken up ('Versuchs-Stationen,' vol. 32, p. 201). One of his soils contained 0·804, and the other 0·367 per cent. of nitrogen; whilst the surface soil of the lucerne plot at Rothamsted contained only about 0·122, and the subsoil, which is assumed to have yielded large quantities of nitrogen to the crops, little more than 0·04 per cent. Again, in the one case, Loges found 40 per cent., and in the other 22·6 per cent., of the total nitrogen taken up. It is obvious, therefore, that such an action is not directly comparable with that of root-sap on a poor subsoil.

Loges states that in experimenting with a great variety of soils he has always found the hydrochloric acid extract gave the phosphotungstic precipitate, from which it is concluded that the substance taken up is an amide or peptone body.

Still more recently, MM. Berthelot and André ('Compt. Rend.,' vol. 103, 1886, p. 1101) have published the results of experiments to determine the character of the insoluble nitrogenous compounds in soils, and of the changes they undergo when acted upon by hydrochloric acid of various strengths, for shorter or longer periods, and at different temperatures. They found the nitrogen in the extract existed partly as ammonia, but in much larger proportion as soluble amides, and that the amounts obtained for both increased with the strength of acid, the time of contact, and the temperature. They also call attention to the fact that when the clear filtered acid extract is exactly neutralised by potash, one portion of the amide still remains soluble, whilst another is precipitated, showing that the amides rendered soluble constitute two groups. Such re-precipitation is quite in accordance with the results obtained in our own experiments, in which less nitrogen remained dissolved after twenty-four hours, than after only one hour's contact, when, with the longer period, the acidity of the extract became neutralised.

As in Loges' experiments, so in those of MM. Berthelot and André, the strength of acid used was in all cases much greater than in that of the Rothamsted experiments, and very much greater than is likely to occur in any root-sap. Further, the soil they operated upon was about four times as rich in nitrogen as the Rothamsted subsoils, whilst with the strongest acid, and a temperature of 100° C., about one-fourth of the total nitrogen of the soil was dissolved.

Still, the results of Loges, and of Berthelot and André, are of much

interest as confirming the supposition that the insoluble nitrogenous compounds in soils are amide bodies, and as indicating the changes to which they are subject when acted upon by acids. Supposing the acid root-sap so to act on the insoluble organic nitrogen of the soil and especially of the subsoil, as already said, the question still remains, whether the amide rendered soluble is taken up as such, or undergoes further change before serving as food for the plant? It is seen that ammonia is an essential result of the reaction; and as, so far as our experiments go, nitric acid seems to be a more prominent constituent of the root-sap than ammonia, the question arises whether the liberated ammonia is not oxidated into nitric acid before being taken up? Then, again, is the soluble amide subjected to further change—perhaps first yielding ammonia, and this again nitric acid? On this supposition we are again met with the difficulty as to the sufficient aëration of the subsoil.

Supposing any considerable amount of the amide rendered soluble may be taken up by the plant as such, it is obviously of interest to consider what is the evidence bearing on the question whether plants can take up such bodies and assimilate their nitrogen? The conditions of experiment and the results obtained by various experimenters, have therefore been considered. The substances which have been experimented upon are—urea, uric acid, hippuric acid, guanine, phosphate of ammonia, glycocoll, creatine, and tyrosin. In some cases the experiments have been made in soil, but in most by the water-culture method.

In the majority of cases there could be little doubt that the complex nitrogenous body contributed nitrogen to the plant, either directly or indirectly. In the case of the experiments with soil as a matrix, there was no direct evidence that the plant took up the complex organic body, as such; and the probability is that it suffered change before becoming available. In some of the water-culture experiments, especially when urea was used, that substance was found within the plant, and it was concluded that it contributed directly as a source of nitrogen to it. Hampe also concluded that glycocoll was as available as nitric acid as nitrogenous food to plants.

Upon the whole it seems probable, that green-leaved plants can take up soluble complex nitrogenous organic bodies, when these are presented to them under such conditions as in water-culture experiments, and that they can transform them, and appropriate their nitrogen. If this be the case, it would seem not improbable that they could take up directly, and utilise, amide bodies rendered soluble within the soil by the action of their acid root-sap.

In connexion with the subject of the conditions under which the insoluble organic nitrogen of soils and subsoils may become available to chlorophyllous plants, some results of Frank may be briefly con-

sidered. He observed that the feeding roots of certain trees were covered with a fungus, the threads of which forced themselves between the epidermal cells into the root itself, which in such cases had no hairs, but similar bodies were found external to the fungus-mantle, which prolonged into threads among the particles of soil. In the case of the Cupuliferæ the occurrence seemed to be universal, and it was to a great extent limited to them, though it has been observed on willows, and on some conifers. The development was the greatest in the first few inches or richer layers of soil. Frank considered the action to be one of true symbiosis, and concluded that the chlorophyllous tree acquires its soil nutriment through the agency of the fungus.

Here, then, is a mode of accumulation by some green-leaved plants which allies them very closely to fungi themselves; indeed, it is by an action on the soil which characterises non-chlorophyllous plants, that the chlorophyllous plant acquires its soil supplies of nutriment. But inasmuch as the action is the most marked in the surface layers of soil rich in humus, and it is stated that the development has not been observed on the roots of any herbaceous plants, the facts so far recorded do not aid us in the explanation of the acquirement of nitrogen by deep and strong rooted Leguminosæ from raw clay subsoils. Still, in view of the office within the soil which is by some attributed to micro-organisms, and other low forms, the observations are not without interest.

Only very brief reference can be here made to the numerous experiments which have been conducted in recent years, the results of which are held to afford evidence that free nitrogen contributes to the yield in our crops—either through the agency of the plant itself, or of the soil under the influence of micro-organisms, or of other non-chlorophyllous forms.

Some years ago, Berthelot called in question the validity of the conclusions from the experiments of Boussingault, ourselves, and others, in which it was sought to determine whether plants assimilated the free nitrogen of the atmosphere, by growing them in enclosed vessels which excluded the possibility of electrical action within the plant or the soil. It is at any rate coincident with the pretty general acceptance of this objection, which obviously puts out of court more exact methods, and exposes the experimenter to many more possible sources of error, that there has been a great accession of experimental evidence adduced, which is held to show the participation of the free nitrogen of the atmosphere in the results of growth. Had the results so obtained by various experimenters been at all accordant one with another, the fact might have been considered proof that the objection was fully justified. They are, however, in a quantitative point of view, so conflicting, without any adequate explanation in the methods

described, that it is impossible to accept the whole as they stand, and for the present it seems necessary to hold judgment on them in abeyance.

The various results alluded to will be discussed in some detail in our full paper, but we can only briefly refer here to some of the various modes of explanation which have been suggested.

In the experiments of M. Berthelot, in all of which the gains of nitrogen are comparatively small, they have in some cases been attributed to electrical action, and in others to the action of micro-organisms within the soil.

Frank, experimenting with a soil very rich in nitrogen, found a loss of combined nitrogen; but, in the case of vegetation experiments, with a less rich soil, he generally found a gain. He concluded that two opposite actions are at work within the soil—one by which nitrogen is set free, and another by which it is brought into combination; the latter being favoured by the presence of living plants. He admits that there is no decisive evidence how this takes place; but he seems to assume that it is under the influence of micro-organisms.

Hellriegel, again, found that lupins did not grow well in an experimental soil, until he added to it the watery extract of a soil from a field where lupins were growing luxuriantly. After this, his experimental plants also grew well, developed the well-known nodules on their roots, and showed a gain of nitrogen. This, he suggested, was probably due to the action of the nodules within the soil, bringing the free nitrogen of the air into combination, and thus rendering it available to the growing lupins. The results of Tschirch and those of Brunchorst have, however, been held to be conclusive against such a view. According to their experiments, the nodules have no external communication with the soil, but receive their nutriment from the plant itself. On this point it is of interest to observe that, according to the recent experiments of Mr. Marshall Ward, on the death of the nodules the spores become distributed in the soil, and, if this be the case, the possibility of some action, whatever that may be, is not yet disproved.

Whatever may be the exact facts in the cases cited, it is at any rate clear that recent lines of explanation of the mode in which some of the higher plants derive their nitrogen involve the supposition of the intervention of lower organisms in some way. It must, however, be admitted on a review of the conflicting results at present at command, that they do not justify any confident conclusion that the compensations supposed do take place in any important degree, or that free nitrogen is to any important extent brought into combination under the influence of the lower organisms. In the meantime it seems not inappropriate to devote attention to some other aspects of the subject.

We would submit that a careful consideration of the history of

agriculture, both ancient and modern, fails to afford evidence of compensation such as is now sought for. Indeed we would say, as we have done before, that—"The history of agriculture throughout the world, so far as it is known, clearly shows that a fertile soil is one which has accumulated within it the residue of ages of previous vegetation, and that it becomes infertile as this residue is exhausted."

In conclusion, we would call attention to the fact, that in the Rothamsted soil and subsoil, down to the depth at which the action of roots has been proved, there exists a store of about 20,000 lbs. per acre of already combined nitrogen. It is true that many soils will contain much less, but many much more. There is then obviously still a wide field for inquiry as to whether or not, or in what way, the very large store of already existing combined nitrogen may become available to growing vegetation. We have indicated some of the lines of investigation which we are ourselves following up; and we would submit that, whether or not the lower organisms may be proved to have the power of bringing free nitrogen into combination, it would at any rate be not inconsistent with well-established facts, were it found that the lower serve the higher by bringing into an available condition the large stores of combined nitrogen already existing, but in a comparatively inert state, in our soils and subsoils.

HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,

ON THE

GROWTH OF ROOT-CROPS

FOR MANY YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JULY 27, 1887,

AT THE

ROYAL AGRICULTURAL COLLEGE,

CIRENCESTER,

BY

J. H. GILBERT, M.A., LL.D., F.R.S.,

SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD,

AND

HONORARY PROFESSOR OF THE COLLEGE.

FROM THE "AGRICULTURAL STUDENTS' GAZETTE,"
NEW SERIES—VOL. III. PART V.

NOTE.—To the Lecture as delivered some additions have been made for publication in the *Agricultural Students' Gazette*, and to the reprints from the *Gazette* a General Summary has been added.

RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF ROOT-CROPS, FOR MANY YEARS IN SUCCESSION ON THE SAME LAND.

CONTENTS.

	PAGE
INTRODUCTION	1
EXPERIMENTS WITH NORFOLK WHITE TURNIPS	3
EXPERIMENTS WITH SWEDISH TURNIPS	8
EXPERIMENTS WITH SWEDISH TURNIPS IN ROTATION	14
EXPERIMENTS WITH MANGEL WURZEL	20
NITROGEN RECOVERED IN INCREASE OF CROP FOR 100 SUPPLIED IN MANURE	26
COMPOSITION OF DIFFERENT DESCRIPTIONS OF ROOTS, AND THEIR VALUE AS FOOD FOR STOCK	31
SUMMARY AS TO THE COMPOSITION, AND THE FEEDING QUALITIES, OF ROOTS	42
GENERAL SUMMARY AND CONCLUSIONS	45

INTRODUCTION.

In my lecture here two years ago, I gave an account of the experiments at Rothamsted on the growth of wheat for more than forty years in succession on the same land, without manure, with farmyard manure, and with a great variety of artificial manures; and last year I gave an account of somewhat parallel experiments on the growth of barley, for more than thirty years in succession on the same land.

On the present occasion I propose to direct attention to the results of experiments on various root-crops, which have also been grown for many years in succession on the same land; in fact, with the exception of the three years, 1853, 1854, and 1855, from 1843 up to the present time; comprising, therefore, a period of 45 years, in 42 of which roots have been grown.

Hitherto, then, the conditions of growth, and the composition, especially so far as this is influenced by those conditions, of certain crops of the great gramineous family cultivated for their seeds, and which are therefore allowed to fully ripen, have been considered.

The remarkable fact was brought out, that these gramineous crops, which, when ripe, contain a low percentage of nitrogen in their dry substance, and accumulate a comparatively small amount of it over a given area, are nevertheless specially benefited by the application of nitrogenous manures; whilst leguminous crops, which not only contain a much higher percentage of nitrogen in their dry substance, and yield a much greater amount of it over a given area, are not specially benefited by nitrogenous manures. This was not supposed to indicate that they relied on the atmosphere for their nitrogen; but to be connected with a different character and range of roots, by virtue of which these

plants—the Leguminosæ—are enabled to avail themselves of soil-sources of nitrogen of which the Gramineæ are unable to take advantage.

The *Root-crops*, the conditions of growth, and the composition, of which we have now to consider, include members of more than one Natural Family of Plants; and they are grown, not for their seed, but for, so to speak, certain intermediate parts and products, which are, by cultivation, very abnormally developed; whilst the crops are not allowed to ripen, but are taken when in a succulent and immature condition. We shall thus have interesting points of comparison, or contrast, brought out, as to the conditions of growth of these crops, and of those to which we owe the cereal grains.

The crops to which I shall specially direct attention are some varieties of turnips, belonging to the order Cruciferæ, and a variety of beet, namely, the feeding mangel, of the natural order Chenopodiaceæ.

The introduction of turnips into our agricultural rotations may be said to have been one of the most important improvements of recent times. The growth of the crop constitutes, indeed, an essential element, not only in the ordinary four-course rotation, but in all our varied rotations.

From certain characters of the turnip plant, especially its abundant leaf-surface, and from certain conditions of its growth, it has frequently been assumed that it is largely dependent on the atmosphere for its nitrogen; and that it is, in fact, thus a collector of nitrogen for the crops grown in alternation with it. But we shall see that experimental evidence does not support this conclusion; and that we must look in other directions for an explanation of the undoubted benefits of the growth of root-crops in rotation.

The object to be attained in the cultivation of root-crops is, it should be remembered, to encourage, by artificial means, a quite abnormal development of a particular part of the plant. If the turnip plant were grown for its natural seed-product, oil, a heavier soil would be more suitable than when the object is to develop the swollen root; in our climate a biennial habit would be induced, and it would be so grown as to be exposed to the summer temperature at a later stage of the development, or life history, of the plant—that is at the seed-forming and ripening period. Under these circumstances there would be much less of fibrous root distributed through the surface soil, the main root would be much less bulbous, and more fusiform, tapping rather than spreading laterally; the leaves and stem would be much larger, both actually and proportionally to the root, and the enlarged root itself would serve as a store of material for the second or final growth.

To obtain the cultivated root, however, as grown as a food and rotation crop, the conditions required are very different. The seed is sown at a different period, and the character of the manuring, and of the season of growth chosen, are, in their conjoint influence, such as to favour a very abnormal accumulation of the store material of the root, and to secure that this development shall attain a maximum within the limits of the season.

It is no objection to what has been said, that, in selecting plants from which to grow seed, for the future growth of the cultivated root, those having the most symmetrical roots are chosen, rather than such as are more tapping, and betray a more characteristic seed-forming tendency. In this case it is not the most abundant natural seed that is the object of culture, but a seed having a special habit of growth, which habit it is desired to propagate. Yet it will be seen how very soon the cultivated turnip will revert to its more natural characteristics, if the mode of culture be not such as to favour the artificial development.

It is well to state these general facts before entering upon any detailed illustrations, the bearings of which will be better understood, if the essentially artificial conditions of growth which are induced be clearly borne in mind.

The first results I shall adduce are those of experiments with a variety of the common turnip, or Brassica rapa—the *Norfolk White*.

EXPERIMENTS WITH NORFOLK WHITE TURNIPS.

Every one knows that root crops—whether common turnips, swedish turnips, or mangel wurzel—are, in ordinary practice, grown by the aid of large dressings of farmyard manure; with, or without, artificial manures in addition; the farmyard manure being, in some cases, applied for the preceding grain-crop, but more generally directly for the root-crop itself. It will be well, therefore, briefly to refer to the results obtained with Norfolk white turnips, by the use of farmyard manure, at the rate of 12 tons per acre per annum, for three years in succession; and, for comparison, those obtained in the same seasons without manure, are also given.

TABLE I.

Produce of Norfolk White Turnips, without Manure, and with Farmyard Manure.

Seasons.	Roots.		Leaves.	
	Without Manure.	With Farmyard Manure.	Without Manure.	With Farmyard Manure.
	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
1843	4 3¾	9 9½	Not weighed.	Not weighed.
1844	2 4½	10 15½		
1845	0 13¾	17 0¾	0 14½	7 7¾
Mean	2 7½	12 8½		

Thus, then, the produce of this assumed restorative crop, when grown without manure, goes down in the third year to 13¾ cwts. per acre; whilst in the third year with farmyard manure there was more than 17 tons.

By the use of 12 tons of farmyard manure per acre per annum for three years in succession, an average produce of about 12½ tons of

roots was obtained. But the amount varied very much indeed according to season; it being nearly twice as great in the third year as in the first. Accumulation of manure in the soil would aid this result, as the season was very favourable for the growth of the crop; but the accumulation, without the favourable conditions of season, would not have sufficed.

It may be observed that the first season, 1843, was characterised by great vicissitudes of both rainfall and temperature; 1844 was both hot and dry at the commencement, with too little total rain till October; whilst the season of most luxuriant growth, 1845, had a sufficient amount, and considerable continuity of rain, and only moderate temperatures, throughout.

Now, farmyard manure, which has yielded these amounts of produce, contains more or less of every constituent required for the growth of the turnip; and of some very important manurial matters, the amount of manure applied would contain much more than did the crop yielded. This would be the case so far as the nitrogen, and most of the mineral constituents, are concerned. Of nitrogen, for example, the 12 tons of farmyard manure would probably contain from 160 to 170 lbs., whilst the average produce of 12½ tons of roots would probably not contain one-third as much. It is true that the leaf, as we shall presently see, would also have accumulated in it a considerable quantity of nitrogen; but besides this a large proportion of that supplied in the manure would remain in the soil in a condition only slowly available to vegetation.

It is to these facts—the large amount of farmyard manure generally applied for the growth of root-crops, the large amount of the nitrogen, and other constituents, remaining in the leaf, which serve directly as manure again, and the large proportion of the constituents of the manure itself which remain and slowly become available to succeeding crops,—that the value of the root-crop in rotation is largely to be attributed.

But another very important factor is, that these crops are, so to speak, gross-feeders, or rapid converters of manure into vegetable produce, and when the edible portion—the root—is consumed by store or fattening stock, a very small proportion of the nitrogen, and other constituents valuable as manure, is retained by the animal. The remainder, perhaps more than 90 per cent. of the nitrogen, is voided by the animals, and becomes manure again. When, however, roots are consumed for the production of milk, a much larger proportion is lost to the manure.

To sum up: a large amount of the manure is converted into vegetable substance, but a still larger amount remains in the soil for future crops; the substance grown provides a large amount of food for animals, but the greater proportion of its constituents remains, or returns, as manure again. Lastly, in addition to these advantages, the opportunity which the growth of the crop affords for the cleaning of the land, constitutes another important element of value.

The next question to consider is—which constituent, or class of constituents, of the complex material, *farmyard manure*, has the most characteristic influence on the growth of the root crop?

Table II. gives some illustrations on this point. It shows the average yield, over four consecutive seasons, 1845-48, of roots, of leaves, and of total produce, of Norfolk white turnips, grown without manure, and with a variety of artificial manures. The upper division of the Table shows the produce without mineral manure, and the lower division shows in each case the mean produce of three different mineral manures, namely, 1—Superphosphate of lime (plot 5); 2—Superphosphate and potash salt (plot 6); 3—Superphosphate, and potash, soda and magnesia salts (plot 4).

TABLE II.

NORFOLK WHITE TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, four seasons, 1845-'48.

Manures and produce per acre per annum.

	SERIES 1. No Nitrogenous Manure.	SERIES 3. Ammonium Salts = 45 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 135 lbs. Nitrogen.	SERIES 5. Rape Cake = 90 lbs. Nitrogen.
WITHOUT MINERAL MANURE. (Three years only, 1846-'48).				
	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
Roots	1 4	1 7	5 10	6 11
Leaves	0 17	1 0	3 19	3 3
Total	2 1	2 7	9 9	9 14
WITH VARIOUS MINERAL MANURES.				
Roots	8 4	9 18	10 5	11 0
Leaves	2 14	4 6	6 3	4 12
Total	10 18	14 4	16 8	15 12

In the upper part of the first column are given the results without manure, and in the lower part of it those with the mineral manure alone; in the second column those with ammonium-salts, in addition, supplying 45 lbs. of nitrogen per acre per annum; in the third those with rape cake and ammonium-salts in addition = 135 lbs. nitrogen per acre; and in the fourth those with rape cake = 90 lbs. nitrogen per acre per annum in addition.

The first point to notice is—that on some of the manured plots there is an average of about 11 tons of roots, and more than 4½ tons of leaves, giving a total produce per acre of more than 15½ tons. *Without manure*, on the other hand, this assumed *restorative crop* yields

an average of only 1 ton 4 cwts. of roots, 17 cwts. of leaves, and a total produce of only 2 tons 1 cwt. The character of the unmanured root was, moreover, totally different. It had more the shape of a carrot than of a turnip; whilst its composition was also totally different from that of the cultivated root.

The difference, both in the amount of produce and in the composition of the cultivated as compared with the more natural root, is strikingly illustrated by the following figures, which relate to the crops of the third season of the experiments, 1845. Thus we have :—

	Roots per acre.		Nitrogen per cent. in Dry Matter.
	Tons.	Cwts.	Per cent.
Without Manure...	0	13¾	3·31
Farmyard Manure	17	1	1·56
Superphosphate of Lime	11	2	1·52

That is to say, under the influence of manure there is a very large amount of non-nitrogenous substance accumulated, diluting, so to speak, the high percentage of nitrogen of the natural, uncultivated root. Not that more nitrogen is not also taken up by the cultivated plant, but in it there is, in proportion to the nitrogen, a large amount of other matters formed, the accumulation of which converts the plant into an important food-crop.

It will be seen that even mineral manures alone, and it is especially those which contain phosphates, have a very marked effect in inducing such accumulation; and it is pre-eminently by the action of such manures that a great amount of fibrous root is developed in the surface soil, under the influence of which more nitrogen, and at the same time more mineral matters, are taken up.

The results in the other columns of Table II. show, that the addition of nitrogenous manure, whether as ammonium-salts, or as rape-cake, or both, gives a further increase in the produce of the roots. But the second line of each division of the Table shows that a prominent effect of the nitrogenous manures is largely to increase the production of leaf. Thus, the average amount of leaf is increased from 2 tons 14 cwts. by mineral manure alone, to 4 tons 6 cwts. with ammonium-salts in addition, to 4 tons 12 cwts. with rape-cake in addition, and to 6 tons 3 cwts. with both ammonium-salts and rape-cake in addition.

The next Table, III., shows, first the average proportion of leaf to 1000 of root, under the four characteristically different conditions as to manuring. It also shows the percentages of dry matter in the roots and leaves respectively; and the percentages of nitrogen and of total mineral matter (ash) in the dry matter. In the lower division of the Table are given the amounts per acre of each of these constituents, in the roots and leaves respectively, and the amounts per acre more or less in the leaf than in the root.

TABLE III.

NORFOLK WHITE TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf.

Per cent. and per acre.

Mean of plots 4, 5, and 6; four years, 1845-1848.

	SERIES 1. No Nitrogenous Manure.	SERIES 3. Ammonium Salts = 45 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 135 lbs. Nitrogen.	SERIES 5. Rape Cake = 90 lbs. Nitrogen.
LEAF TO 1000 ROOT.				
	329	434	600	418
PER CENT.				
Dry Matter — In root	8·54	8·07	7·66	7·96
Dry Matter — In leaf	14·56	13·54	12·43	12·94
Nitrogen in Dry — In root	1·60	2·64	2·45	1·78
Nitrogen in Dry — In leaf	3·75	3·68	(3·68)	(3·68)
Mineral in Dry — In root	7·26	8·22	9·03	8·30
Mineral in Dry — In leaf	12·24	11·88	11·12	11·87
PER ACRE, lbs.				
Dry Matter — In root	1581	1807	1770	1963
Dry Matter — In leaf	853	1289	1703	1296
Dry Matter — Leaf + or − root	− 728	− 518	− 67	− 667
Nitrogen — In root	25	48	43	35
Nitrogen — In leaf	32	48	63	48
Nitrogen — Leaf + or − root	+ 7	0	+ 20	+ 13
Mineral Matter — In root	118	148	160	165
Mineral Matter — In leaf	100	151	187	151
Mineral Matter — Leaf + or − root	− 18	+ 3	+ 27	− 14

Thus, with the *Norfolk White Turnip*, we have from less than one-third as much leaf as root without nitrogenous manure, to nearly two-thirds as much with the largest supply of nitrogen by manure—that is with the greatest luxuriance of growth.

The economic importance of the difference in the proportion of leaf to root, not only under the influence of different conditions as to

manuring, but in different descriptions of root-crops, will be rendered obvious by the other results given in the same Table, and similar results given in corresponding Tables relating to *Swedish Turnips* and to *Mangel Wurzel*.

First as to *Norfolk White Turnips*:—not only is there the large proportion of leaf, but the leaf contains a very much higher percentage of dry matter than the root; and there is a very much higher percentage of both nitrogen and total mineral matter in the dry substance of the leaf.

The significance of these facts is more clearly brought out in the lower division of the Table, which shows the amounts per acre, in root and in leaf, respectively, of dry matter, of nitrogen, and of total mineral matter, under the different conditions of manuring; also the amounts of these in the leaf + or − the amounts in the roots.

It is seen that, owing to the much higher percentages of dry matter, and of nitrogen and mineral matter in the dry matter, of the leaf, the proportion of these in the leaf per acre, is much greater than is indicated by the proportion of the fresh leaf itself. We have, in fact, in one case, that with the highest nitrogenous manuring, nearly as much dry or solid matter per acre in the leaf, which for the most part only becomes manure again, as in the edible part of the crop, *the root*. In three cases there is actually more of the nitrogen of the crop in the leaf, remaining for manure, than there is in the portion available as food. There is also, in two cases, more of total mineral constituents in the leaf than in the root.

EXPERIMENTS WITH SWEDISH TURNIPS.

We will now turn to the consideration of similar particulars relating to other descriptions of Roots, and among these I will first direct attention to another very typical root-crop, namely the *Swedish Turnip*, Brassica campestris rutabaga.

The illustrations adduced are drawn from results obtained in the same field, on the same plots, and with, to a great extent, similar manures, as in the case of the Norfolk White Turnip already considered. The mineral manures were in fact practically the same throughout, and the nitrogenous manures were nearly the same in the first two of the four years, 1849 and 1850, but in the second two no nitrogenous manures were used. Further, the results were obtained in the next succeeding four years to those in which the Norfolk Whites were grown.

Table IV. shows the average amounts of produce—roots, leaves, and total—under the different conditions of manuring, over the four years, two with and two without nitrogenous manures; and Table V. shows the proportions of leaf to root, the percentage of dry matter, and the percentages of nitrogen and of mineral matter in the dry matter, in each; also the amounts of dry matter, nitrogen, and mineral matter per acre, in leaf and in root, respectively.

Compared with the produce of the White Turnip, that of the Swedish Turnip shows upon the whole rather less root without

nitrogenous manure, that is with the mineral manure alone, owing to the gradual exhaustion of the nitrogen of the soil where none had been applied by manure for a number of years. But on the other hand there is, with nitrogenous manures, in two cases out of three, more of the Swedish than of the White Turnip root.

TABLE IV.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, four seasons, 1849-'52.

Manures and produce per acre per annum.

	SERIES 1. No Nitrogenous Manure.	SERIES 3. Ammonium Salts = 43 lbs. Nitrogen. ('49 & '50 only.)	SERIES 4. Ammonium Salts and Rape Cake = 141 lbs. Nitrogen. ('49 & '50 only.)	SERIES 5. Rape Cake = 98 lbs. Nitrogen. ('49 & '50 only.)
WITHOUT MINERAL MANURE.				
	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
Roots	2 6	3 17	7 0	7 14
Leaves (1)	0 6	0 6	0 17	0 13
Total	2 12	4 3	7 17	8 7
WITH VARIOUS MINERAL MANURES (Plots 4, 5, and 6).				
Roots	7 5	8 18	12 2	11 9
Leaves (1)	0 10	0 11	0 19	0 15
Total	7 15	9 9	13 1	12 4

(1) Average of three years only, 1850-'52, leaves in 1849 not weighed.

A very important point to notice is, that there was, even when there was more root, very much less leaf in the case of the Swedish Turnip. Thus, whilst with the highest nitrogenous manure there was, with an average of 10¼ tons of the White Turnip roots nearly 6¼ tons of leaves, there was with the Swedish Turnip, with more than 12 tons of roots, not quite one ton of leaf. Here, then, the result of growth is that almost the whole of the accumulation is in the food-product, the root; and a very insignificant amount remains in the leaf, most of it simply to become manure again.

This point will be more clearly illustrated by the results given in Table V. But before turning to it, it may here be observed, though the fact is not shown in the merely mean results given in the Table, that there was very little influence from potash manures, excepting where, with the aid of liberal nitrogenous manuring, there was much increased luxuriance, and with this a greater drain on the stores of potash of the soil itself.

Let us now turn to the results in Table V., which gives the leaf to 1000 root, and the same particulars as before relating to the percentage composition of each, and to the amounts of the selected constituents *per acre* in each.

TABLE V.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf,
Per cent. and per acre.
Mean of plots 4, 5, and 6; four years, 1849-1852.

	SERIES 1. No Nitrogenous Manure.	SERIES 3. Ammonium Salts = 43 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 141 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
LEAF TO 1000 ROOT.				
	69·0	61·8	78·5	65·5
PER CENT.				
Dry Matter — In root	11·59	11·51	10·54	10·89
Dry Matter — In leaf	13·81	13·08	12·97	13·19
Nitrogen in Dry — In root	1·40	1·69	2·19	1·84
Nitrogen in Dry — In leaf	3·95	4·07	4·11	4·00
Mineral Matter in Dry — In root	4·38	4·49	4·83	4·66
Mineral Matter in Dry — In leaf	12·16	11·85	10·54	10·59
PER ACRE, lbs.				
Dry Matter — In root	1879	2245	2840	2769
Dry Matter — In leaf	154	166	270	227
Dry Matter — Leaf + or − root	− 1725	− 2079	− 2570	− 2542
Nitrogen — In root	26	38	62	51
Nitrogen — In leaf	6	7	11	9
Nitrogen — Leaf + or − root	− 20	− 31	− 51	− 42
Mineral Matter — In root	83	102	139	130
Mineral Matter — In leaf	19	20	29	24
Mineral Matter — Leaf + or − root	− 64	− 82	− 110	− 106

It is seen that, instead of 300 to 600 parts of leaf for 1000 of root, as in the White or Common Turnip, we have, with the Swedish

Turnip, in no case 100 of leaf to 1000 of root. The highest proportion is 78½ to 1000, and this is with the highest nitrogenous manuring, and the most luxuriant crops.

It is further seen that the percentage of dry matter in the root ranged from 10½ to 11½, whilst in the White Turnip it averaged only about 8 per cent. We have, therefore, not only a larger proportion of edible root, but that root contains a larger proportion of solid matter or food material.

As with the Norfolk White, however, so also with the Swedish Turnip, the leaf contains a much higher percentage of dry substance than the root, and that dry substance contains a much higher percentage of both nitrogen and total mineral matter than does the dry substance of the root.

The lower division of the Table shows, especially when compared with the corresponding particulars relating to the Common Turnip, how very different are the two crops in some very important respects. Thus, with the Swedish Turnip we have, with the highest manuring, fully one and a half time as much dry substance per acre in the root; that is one and a half time as much food produced per acre, as with the Common Turnip. We have a quite insignificant amount of matter accumulated and remaining in the leaf, that is for the most part only serving as manure again.

Of the nitrogen again, there is, under all conditions of manuring, even those giving the greatest luxuriance, a very small proportion remaining in the leaf. The same is the case with the total mineral matter.

The question obviously suggests itself, if the Swedish Turnip has all these advantages over the numerous varieties of the so-called Common Turnip, why are these ever grown? why not always the Swedish Turnip?

In the first place, soil and season have to be taken into account. Then the economy of the farm requires that descriptions should be selected that can not only be sown in due succession, but which will mature at different periods, so as to supply food for stock in due succession, and also frequently to get the crop early off the land, to leave it free for some other crop. Again, a comparatively large proportion of leaf serves as protection against frost while the crop is still in the field; and the storing qualities of the root have to be considered in connection with the character of the seasons of the locality. For example, on the light soils of Norfolk, which are very favourable for the development of root, and but little for that of leaf, and where the roots can be largely consumed by sheep on the land, without injury to its mechanical condition, the Swedish Turnip is the predominant root. In the north east and east of Scotland, on the other hand, several varieties of Yellow Common Turnips are grown in much larger proportion, and a large amount of leaf is not recognised as a disadvantage. And here it may be observed, that the higher the nitrogenous manuring, and the heavier the soil, the greater is the tendency to produce a large

amount of leaf. Further, as a rule, the larger the amount of leaf remaining vigorous at the time the crop is taken up, the less fully ripe will be the roots; and, within limits, it is desirable with a view to the storing qualities of the root, that it should not be too ripe.

After the four crops of Swedish Turnips had been taken from the land, barley was grown for three years in succession without any manure, in order, as far as possible, to equalise the condition of the various plots, as affected by the previous manuring.

It will suffice to say that the results clearly showed that there had been accumulation where rape-cake had been applied.

Then, for five years in succession (1856-60), Swedish Turnips were again grown on the comparatively exhausted plots, much on the same plan as before, but with smaller amounts of nitrogen supplied. No special interest attaches to the results over these five years for our present purpose.

I now pass to the consideration of the average results obtained over the next ten years, 1861-1870, again with Swedish Turnips. During this period larger quantities of nitrogen were again applied; but for mineral manure superphosphate of lime was used alone, that is without any further addition of either potash, soda, or magnesia. The average produce per acre on the different plots over the 10 years is given in Table VI.

TABLE VI.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and Manures.

Mean of ten seasons, 1861-'70. Manures and Produce per acre per annum.

	SERIES 1. No Nitrogenous Manure.		SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.		SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.		SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.		SERIES 5. Rape Cake = 98 lbs. Nitrogen.	
	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.
WITHOUT MINERAL MANURE.										
Roots	0	11	1	1	0	13	4	9	4	15
Leaves ...	0	3	0	5	0	3	1	0	0	18
Total ...	0	14	1	6	0	16	5	9	5	13
WITH SUPERPHOSPHATE OF LIME (Plots 4, 5, and 6).										
Roots	2	9	5	8	4	9	7	9	6	8
Leaves ...	0	9	1	0	0	17	1	14	1	3
Total ...	2	18	6	8	5	6	9	3	7	11

The results of these experiments are little more than confirmatory of those which have gone before; but the amounts of produce are throughout on a lower level. This can only in part be attributed to the exclusion of potash from the manures. It is doubtless mainly due to the incidental circumstance that in growing the same description of crop, with the same comparatively limited and superficial root-range, for so many years in succession, the surface soil became less easily worked, and the tilth, so important for turnips, was frequently unsatisfactory; whilst for want of variety and depth of root-range of the crop, a somewhat impervious pan was formed below.

This fact is, however, of itself of considerable interest, as indicating one important and very beneficial influence of a rotation of crops. Indeed, we shall presently see, that even the change to another description of root-crop, with a totally different and much more extended root-range, is accompanied with a much increased production over a given area by the use of the same manures.

Looking to the Table (VI.), it is seen that there are now five series of Plots instead of only four; nitrate of soda being applied on series 2, in amount supplying the same quantity of nitrogen as in the ammonium-salts on series 3. The result is a greater produce of both root and leaf than with the ammonium-salts.

The superphosphate alone (see lower division of column 1) gives less produce than the mineral manures in the series of four years before considered, doubtless to a great extent owing to the still further exhaustion of the available nitrogen of the surface soil. In fact the surface soils in question showed, on analysis, lower percentages of nitrogen than those of any other experimental field at Rothamsted —a result which is quite consistent with the fact of the large amount of feeding-root distributed through the surface soil by the growing turnip.

Again, consistently with this supposition, and with the results that have gone before, there is still very marked, but somewhat reduced effect, from all the nitrogenous manures; and again, the amount of leaf is very small, but it is the greater the higher the nitrogenous manuring, and the greater the luxuriance of growth.

Table VII. shows the proportion of leaf to 1000 of root; also the percentages of dry matter, and of nitrogen and mineral matter in the dry matter; and, as before, the amounts of each per acre, in the roots and in the leaves.

With the soil gradually becoming closer, and less favourable for root development, the proportion of leaf to root is somewhat higher.

It should be explained that the percentages given in parentheses are not the results of direct determinations in each particular case, but are deduced from comparable results. They are, however, undoubtedly near enough to the truth for the purpose of the present illustrations.

Again, we see the much higher percentage of dry substance in the leaf than in the root; also much higher percentages of nitrogen, and of total mineral matter, in the dry substance of the leaf.

TABLE VII.

SWEDISH TURNIPS.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf, Per cent. and per acre.

Mean of Plots 4, 5, and 6; ten years, 1861-1870.

	SERIES 1. No Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
LEAF TO 1000 ROOT.					
	184	185	191	228	180
PER CENT.					
Dry Matter — In root ..	12·04	11·01	11·32	10·94	10·83
Dry Matter — In leaf	14·93	14·46	14·24	13·78	14·66
Nitrogen in Dry — In root... ...	(1·40)	(1·69)	(1·69)	(2·19)	(1·84)
Nitrogen in Dry — In leaf	(3·95)	(4·07)	(4·07)	(4·11)	(4·00)
Mineral in Dry — In root	4·55	5·38	4·71	5·10	5·03
Mineral in Dry — In leaf	11·64	10·62	12·23	11·54	11·27
PER ACRE, lbs.					
Dry Matter. — In root...	629	1285	1084	1777	1511
Dry Matter. — In leaf	146	320	268	498	376
Dry Matter. — Leaf + or − root	− 483	− 965	− 816	− 1279	− 1135
Nitrogen — In root...	8·8	21·7	18·3	38·9	27·8
Nitrogen — In leaf	5·8	13·0	10·9	20·5	15·1
Nitrogen — Leaf + or − root	− 3·0	− 8·7	− 7·4	− 18·4	− 12·7
Mineral Matter. — In root...	28·9	71·1	53·6	94·2	76·6
Mineral Matter. — In leaf	16·8	33·1	32·5	57·5	41·9
Mineral Matter. — Leaf + or − root	− 12·1	− 38·0	− 21·1	− 36·7	− 34·7

Looking to the lower division of the Table, it is seen that there is here again, under all conditions of manuring, much more solid matter *per acre*, in the root than in the leaf. There is also more nitrogen, and more total mineral matter, accumulated in the root; though the proportion of the nitrogen which is accumulated in the leaf is higher than in the previous experiments.

EXPERIMENTS WITH SWEDISH TURNIPS IN ROTATION.

I have now to call attention to illustrations drawn from results of experiments in which Swedish Turnips were grown under conditions

much more nearly allied to those of their cultivation in ordinary farm practice, namely, when grown in the ordinary four-course rotation of—roots ; barley ; clover, beans, or fallow ; and wheat.

The experiments in question commenced in 1848, and they are still in progress, so that the tenth course of four years each, making 40 years in all, is completed with the harvest of this year—1887 ; and the tenth season of turnips was in 1884.

The area under experiment is two and a half acres, divided into three main divisions, respectively under the following conditions as to manuring :—

1.—Unmanured from the commencement.

2.—Superphosphate of lime alone, applied only for the turnip-crop, commencing each course ; that is once every four years. For the tenth course, however, salts of potash, soda, and magnesia, have been applied as well as superphosphate.

3.—A complex manure, only applied every fourth year, that is for the turnip crop, and comprising superphosphate of lime, salts of potash, soda, and magnesia, ammonium-salts, and rape-cake, and supplying about 140 lbs. of nitrogen per acre for each course.

This complex manure was designed to be, in a great measure, a substitute for farm-yard manure, and was used instead of it, in order that the amount of the different constituents supplied might be more accurately known.

It should be further explained that, from one-half of each of the three plots, the turnips, with their leaves, were carted off the land, whilst they were consumed by sheep (or cut and spread) on the other half.

Table VIII. shows the produce of Swedish Turnips, roots, leaves, and total, on each of the two portions of each of the differently manured plots each year.

The first point to remark is that, excepting in the first year, when the land was in somewhat high condition, the produce of roots without manure was, even in rotation, quite insignificant—not amounting to an average of 1 ton per acre over the subsequent years.

Superphosphate of lime alone gives much more—on the average, from eight to nine tons per acre.

This great increase is due largely to the very great development of feeding root within the surface soil under the influence of the phosphatic manure ; and the necessary nitrogen, beyond the small amount of combined nitrogen annually coming down in rain and the minor aqueous deposits from the atmosphere, has doubtless been gathered, under the influence of this increased root development, from the previous accumulations within the soil itself.

By the complex manure, however, supplying, besides phosphate, other mineral constituents, and also a large amount of nitrogen, the crops are still further much increased. There were, indeed, in several cases about, or more than, 20 tons of roots per acre.

TABLE VIII.

Swedish Turnips.

Grown in four-course rotation, Turnips, Barley, Clover or Beans, and Wheat, Agdell Field, Rothamsted.

Ten Courses. Manured for the Turnips only.

QUANTITIES PER ACRE.

	Carted off the Land.						Fed on the Land.					
	Unmanured.		Superphosphate. (1)		Mixed Manure.		Unmanured.		Superphosphate. (1)		Mixed Manure.	
Roots.												
	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.	Tons.	Cwts.
1848	8	15¼	14	12	19	14¾	8	17¾	17	5	21	9
1852	1	6	11	3¼	19	16½	0	19½	12	10½	19	6
1856	1	12	6	16	16	13¾	1	0¼	9	16	17	1¼
1860	0	1	1	9¼	4	7½	0	1	1	18¾	3	12
1864	0	8¾	3	8	8	16¼	0	8½	3	18¾	8	8½
1868	Crop failed											
1872	1	14⅛	8	10⅝	16	19⅞	1	9⅛	9	10⅛	16	10
1876	0	17¼	9	8¼	17	16	1	1	11	5¾	17	19¼
1880	0	14	9	19½	21	19½	1	1	11	3¾	22	6¼
1884	0	5	8	13¼	14	6¾	0	12	10	6	14	0¾
Means of 9 Courses	1	14⅞	8	4½	15	12¼	1	14½	9	14⅞	15	12⅝
Leaves.												
1848	0	19¾	1	15	2	6¼	1	0½	1	19¾	2	6¾
1852	0	4½	1	0½	1	16½	0	3½	1	2	1	13
1856	0	2½	0	7½	0	12½	0	1½	0	14½	0	11¾
1860	(6¼ lbs.)		0	1½	0	3¼	(5 lbs.)		0	1¾	0	4½
1864	0	0¾	0	4¾	0	8¾	0	]	0	4¾	0	8¾
1868	Crop failed.											
1872	0	8¾	0	17⅜	1	15¾	0	7¾	0	19½	1	19
1876	0	5	1	8½	2	15¼	0	5	1	7½	3	3
1880	0	2¼	0	11¾	2	3¼	0	3	0	11	1	18¾
1884	0	3⅛	1	0¼	3	3¼	0	5	1	3	3	3¾
Means of 9 Courses	0	5⅛	0	16¼	1	13⅞	0	5¼	0	18¼	1	14⅜
Total Produce.												
1848	9	15	16	7	22	1	9	18½	19	4¾	23	15¾
1852	1	10½	12	3½	21	13	1	2¾	13	12½	20	19
1856	1	14½	7	3½	17	6¼	1	1¾	10	10½	17	13
1860	0	1	1	10¾	4	10¾	0	1	2	0½	3	16½
1864	0	9½	3	12¾	9	5	0	9½	4	3½	8	17¼
1868	Crop failed.											
1872	2	2⅞	9	8	18	15⅝	1	17½	10	10	18	9
1876	1	2½	10	16¾	20	11½	1	6	12	13½	21	2½
1880	0	16¼	10	11½	24	2¾	1	4	11	14¾	24	5
1884	0	8½	9	13½	17	10	0	17	11	9	17	4½
Means of 9 Courses	2	0	9	0¾	17	6⅛	1	19¾	10	13½	17	6¾

(1) For the tenth course, salts of potash, soda, and magnesia, as well as superphosphate.

But, under each condition as to manuring, there is very great variation in amount of growth from year to year, according to the characters of the seasons. In 1868, indeed, the crop entirely failed on all the plots, although the seed was sown twice. Again, whilst the complex manure yielded about 22 tons of roots in 1880, the very same manure gave only about 4 tons in 1860; the average yield over the nine years being about 15½ tons. Against this, the average yield by superphosphate of lime alone was about 9 tons, and without any manure only about 1¾ tons.

With regard to the comparatively large amount of produce by superphosphate of lime alone, it is of interest to state, in passing, that there is, perhaps, no agricultural practice by which what is termed the *condition* of land, that is the readily available fertility due to recent accumulations, can be to so great an extent exhausted by one crop, as by growing turnips by superphosphate of lime alone; provided, of course, that the season is favourable.

I must not enter into any detail as to the climatal characters of the individual seasons yielding such very different amounts of produce; but it may be stated that the results, like those before referred to, show that not only a considerable amount, but considerable continuity, of rain is required to favour the continuous accumulation of material by these succulent crops, whose office it is to form a large amount of comparatively crude and immature products. These conditions as to moisture being fulfilled, fairly average, or even rather over average temperatures may not be adverse, provided the plant has secured a good start, and has attained a fair amount of vigour. Under the same circumstances, too, lower than average temperatures may still be favourable for such growth.

Table IX. shows for these Swedish Turnips grown in an ordinary course of rotation, on the same plan as in other cases, the proportion of leaf to root, and the percentages, and the amounts per acre, of dry matter, and of certain constituents of the dry matter, in the root, and in the leaf, respectively; and there are now given, besides the percentages and the amounts per acre, of nitrogen and of total mineral matter, those of potash and of phosphoric acid also.

In the first line of figures it is seen that the average amount of leaf to 1000 root is, without manure, relatively high, there being practically no root development. With superphosphate of lime alone, there was little luxuriance, but special tendency to root-formation, and the proportion of leaf is low. With the mixed (mineral and nitrogenous) manure, and great luxuriance, there is a larger proportion of leaf. But in all cases there is a comparatively small proportion, and as before very much less than in the case of the common or White Turnip.

In the next division of the Table are given the *percentages* of dry or solid matter in the root and in the leaf; and the percentages of nitrogen, total mineral constituents, potash, and phosphoric acid, in the dry matter, of root and leaf.

As in the case of the crop when grown year after year on the same

TABLE IX.

Swedish Turnips.

Grown in four-course Rotation. Agdell Field, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf, Per cent. and per acre.

Mean of 9 courses, 1848, '52, '56, '60, '64, '72, '76, '80, and '84.

		Un-manured.	Super-phosphate.	Mixed Manure.
Leaf to 1000 Root.				
		150	96	109
Per cent.				
Dry Matter ...	In root	12·40	11·30	10·61
	In leaf	16·73	15·94	14·80
Nitrogen in Dry	In root	2·82	1·89	2·32
	In leaf	3·90	3·95	4·18
Mineral Matter in Dry	In root	4·52	4·54	5·65
	In leaf	12·91	11·94	11·92
Potash in Dry ...	In root	1·45	1·40	2·31
	In leaf	2·04	1·73	2·94
Phosphoric Acid in Dry.. ...	In root	0·37	0·53	0·58
	In leaf	0·55	0·85	0·90
Per Acre, lbs.				
Dry Matter ...	In root	473	2231	3689
	In leaf	98	279	504
	Leaf + or — root	— 375	— 2002	— 3185
Nitrogen	In root	11·6	40·5	81·8
	In leaf	3·8	10·7	21·2
	Leaf + or — root	— 7·8	— 29·8	— 60·6
Mineral Matter ..	In root	21·4	100·9	205·1
	In leaf	12·0	31·0	59·7
	Leaf + or — root	— 9·4	— 69·9	— 145·4
Potash	In root	6·8	31·0	83·8
	In leaf	1·9	4·5	14·7
	Leaf + or — root	— 4·9	— 26·5	— 69·1
Phosphoric Acid	In root	1·7	11·6	20·9
	In leaf	0·5	2·2	4·5
	Leaf + or — root	— 1·2	— 9·4	— 16·4

land by artificial manures, so now when grown only once in four years in an ordinary course of rotation, and in one case with a complex manure, mineral and organic, and including a liberal supply of nitrogen, thus fairly representing farmyard manure, we have considerably higher percentages of solid matter in the leaf than in the root. We have, also, very much higher percentages of nitrogen and of total mineral matter, and notably higher percentages of both potash and phosphoric acid, in the dry matter of the leaf than in that of the root.

It will be observed that the unmanured roots and leaves show abnormally high percentages of dry matter, and the roots an abnormally high percentage of nitrogen in their dry substance. The percentage of phosphoric acid in the dry substance of both leaf and root was, however, much lower than in either of the other experiments; and as the next results show, it was largely for want of phosphoric acid that the growth was so restricted.

The crops grown by superphosphate of lime alone would be fully ripe, and much riper than those grown by the complex manure, and accordingly both root and leaf show higher percentages of dry substance; whilst, owing to the want of supply of any nitrogen by manure, the superphosphate roots contain a relatively low percentage of nitrogen in their dry substance.

The amounts of constituents per acre, in root and leaf, are given in the lower division of the Table. As in the other cases with Swedish Turnips, there is, under each condition of manuring, and in the case of each of the constituents enumerated, very much more per acre in the root than in the leaf. Leaving the results without manure out of the question, as entirely abnormal, it may be observed that whilst the total produce (roots and leaves) by superphosphate of lime alone, contains less than 23 cwts. of solid matter per acre, that by the complex manure contains nearly 37½ cwts. Of the total solid matter per acre, rather more than ⅘ths of that grown by superphosphate of lime alone, and rather more than ⅞ths of the larger amount grown by the mixed manure, is accumulated in the edible roots.

About twice as much nitrogen was accumulated in the crop grown by the complex manure which supplied it, as by the superphosphate of lime alone; and in each case about ⅘ths of the total nitrogen was in food-product—the root.

There was also very much more of total mineral constituents, and especially of the functionally more important ones, potash and phosphoric acid, taken up under the influence of the full supply, and more luxuriant growth; and, of each of these, several times as much was contained in the root as in the leaf.

These further illustrations in regard to Swedish turnips, therefore fully confirm those which have gone before, in showing that a very much larger proportion of the substance grown is accumulated in the root than in the leaf, than is the case with the common turnips. In fact, all the evidence goes to show that whilst in the case of the common turnips a very large amount of the matter grown only serves

for manure again, in that of the Swedish turnips a very small proportion of the produce is useless as food for stock.

EXPERIMENTS WITH MANGEL WURZEL.

I have now to direct attention to root-crops of very different characteristics from those of the crops contributed by the Natural Order Cruciferæ, and the genus Brassica, namely, to a variety of the Beta vulgaris, of the Natural Order Chenopodiaceæ.

To this Order, and to this species, we owe the many varieties of feeding beet or Mangel-wurzel, and also many varieties of the Sugar-beet. As the Mangel-wurzel is a very important agricultural crop in this country, whilst the Sugar-beet is not, I shall only consider in any detail the results relating to the Mangel.

The results with both crops were obtained in the same field and on the same plots as those on which, first Norfolk Whites, and afterwards Swedish Turnips, were grown year after year on the same land, without manure, and with different descriptions of manure.

The last series of Swedish Turnips grown in that field were in the ten years 1861-1870; and it has been stated that by the continuous growth of the one description of crop, with one character and range of roots, the surface soil had become close, and a somewhat impervious pan was formed below it. After this the land was ploughed more deeply, and Sugar-beet was grown for five years in succession—1871 to 1875 inclusive. Since then, commencing in 1876, and continuing every year up to the present time, 1887, a period of 12 years, Mangel-wurzel has been taken. It is from results obtained in the field during the first eight years, and in the Laboratory during shorter periods, that I shall now draw my illustrations.

Table X. shows, in the same form as previously for the Turnips grown in the same field, the manures applied per acre per annum, and the average produce per acre per annum, on each plot, over the eight years 1876 to 1883 inclusive.

It will be seen that results are now given for six instead of for only four main plots; those for two plots with farm-yard manure being added. Each main plot is, as before, divided into five. The first column gives the results where no cross-dressings of artificial nitrogenous manure were used. The second those obtained with a cross-dressing of nitrate of soda in addition; the third with ammonium-salts in addition; the fourth with ammonium-salts and rape-cake added; and the fifth with rape-cake only added. The upper division shows the produce of roots, the middle division that of the leaves, and the lower division the total produce, roots and leaves together.

A glance at the Table (X.) shows that the produce of roots of the Mangel-wurzel, where nitrogenous manures were applied, is on a much higher level than that of either common or Swedish Turnips; and there is also much more leaf. Speaking generally, there is about twice as much produce of roots per acre as there was of Swedish Turnips with the same manures on the same plots, and the quantity of leaf is more than twice as great.

TABLE X.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures.

Means for 8 seasons, 1876-'83. Manures and Produce per acre per annum.

Plot Nos.		SERIES 1. No Artificial Nitrogenous Manure.		SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.		SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.		SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.		SERIES 5. Rape Cake = 98 lbs. Nitrogen.	
	ROOTS.	Tns.	cwts.	Tns.	cwts.	Tns.	cwts.	Tns.	cwts.	Tns.	cwts.
1	Farmyard Manure	15	10	21	9	22	6	25	1	22	8
2	Farmyard Manure and Superphosphate ...	15	13	23	10	22	1	24	13	22	17
3	No Mineral Manure	4	9	13	17	7	7	11	7	11	6
5	Superphosphate	5	2	16	18	9	10	12	8	12	17
6	Superphosphate and Potassium Sulphate ..	4	10	17	9	14	15	22	10	17	14
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	5	14	19	10	16	1	25	14	19	13
	Means of 6 and 4 ...	5	2	18	10	15	8	24	2	18	14
	LEAVES.										
1	Farmyard Manure	2	16	4	2	5	4	6	5	3	19
2	Farmyard Manure and Superphosphate ...	2	12	4	12	5	8	6	5	4	0
3	No Mineral Manure	1	0	3	5	3	0	4	2	2	18
5	Superphosphate	1	0	3	8	3	4	4	7	3	3
6	Superphosphate and Potassium Sulphate ...	0	18	3	2	2	15	5	8	2	14
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride ..	1	2	3	14	2	15	5	4	3	1
	Means of 6 and 4 ...	1	0	3	8	2	15	5	6	2	17
	TOTAL PRODUCE (ROOTS AND LEAVES).										
1	Farmyard Manure	18	6	25	11	27	10	31	6	26	7
2	Farmyard Manure and Superphosphate ...	18	5	28	2	27	9	30	18	26	17
3	No Mineral Manure	5	9	17	2	10	7	15	9	14	4
5	Superphosphate	6	2	20	6	12	14	16	15	16	0
6	Superphosphate and Potassium Sulphate ...	5	8	20	11	17	10	27	18	20	8
4	Superphos., Pot,, and Magnesium Sulphates, and Sodium Chloride	6	16	23	4	18	16	30	18	22	14
	Means of 6 and 4 ...	6	2	21	18	18	3	29	8	21	11

The Mangel seed is sown earlier, and the plant has a longer period of growth. It has a much more deeply penetrating tap root, throws out a less proportion of its feeding roots near the surface, and exposes a comparatively large area of leaf to the atmosphere. With its more extended root-range, it is less dependent on continuity of rain when growth is once well established; and it bears or rather requires for full growth, a higher temperature than the turnip. The midland, eastern, and southern divisions of the country are therefore much more suitable for the crop than the north-west or north of England, or than Scotland, where it is comparatively little grown. But, where the soil and climate are suitable, very much larger crops can be obtained than of Turnips. The Mangel requires, however, very heavy dressings of farm-yard manure if it is to yield full crops.

The Table X. (p. 21) shows that with farm-yard manure alone, at the rate of 14 tons per acre per annum, there was an average produce of about 15½ tons of roots per acre, and that the addition of superphosphate of lime increased it very little. This result compared with that obtained with Turnips is quite consistent with the difference in the character and range of the feeding-roots of the two crops; and it is also quite accordant with common experience, which has shown that superphosphate is very much less generally beneficial when applied to Mangels.

Notwithstanding the amount of farm-yard manure employed would supply annually about 200 lbs. of nitrogen per acre, it is seen that the addition of specially nitrogenous manures greatly increases the crops; and where the nitrogen is applied in the very rapidly available condition as in nitrate of soda, superphosphate of lime is not without effect. In the nitrate of soda or ammonium-salts, 86 lbs. of nitrogen is supplied per acre annually, and the crops are increased by nearly one-half. Where rather more nitrogen is applied, in rape-cake, in which however it exists in a less rapidly available condition, the amount of increase is much the same as with the nitrate or the ammonium-salts; but with the rape-cake there will be more unexhausted residue remaining in the soil.

Where both rape-cake and ammonium-salts are used in addition to the farm-yard manure, there is an average of about 25 tons of roots per acre per annum over the eight years.

Without manure, or with purely mineral manures, the produce of this more powerfully rooting plant is much higher than was previously obtained with Swedish Turnips on the same plots, notwithstanding that the land had become more exhausted so far as nitrogen is concerned.

The addition of the nitrogenous to the mineral manures in some cases more than quadrupled the produce. A given quantity of nitrogen in the more rapidly available condition, as in nitrate of soda, yielded more increase of crop than the same amount as ammonium-salts.

With the comparatively limited growth of turnips, potash manures had little effect; but here, after years of further exhaustion of the potash within the soil itself, and with so much more vegetable matter produced, the deficiency of potash where it has not been applied is

rendered very obvious by the much less produce obtained where superphosphate was used without potash, than where potash was also supplied in the manure.

Even with the artificial manures, the average produce in several cases approaches 20 tons of roots per acre; in one case where the largest amount of nitrogen was employed there was an average of 22½ tons, and in another of nearly 25¾ tons per acre per annum.

Attention will be called to the proportion of leaf to root further on, but before passing from Table X. it should be noticed that the actual quantity of leaf per acre is comparatively large. Thus it amounts, on some of the farm-yard manure plots, to five or six tons, or even more, which, for the most part, returns to the land at once as manure.

Lastly, on several plots, there was an average annual total produce, root and leaf together, of more than 30 tons. The very great power of utilising manure and producing vegetable substance possessed by the Mangel is thus strikingly illustrated. Indeed, the results amply demonstrate that, great as is the capability of luxuriance of the plant, its full development is pre-eminently dependent on large supplies by manure.

It has been assumed by some, however, that by virtue of the large amount of leaf-surface which root crops expose to the atmosphere, they are enabled to obtain a large amount of their nitrogen from that source. It is further assumed that, if a small quantity of nitrogenous manure is supplied, so as to favour the early development of the plant, it will then obtain the remainder from the atmosphere. The results given in Table XI. afford pretty conclusive evidence against such a view.

There is there given the average produce of Mangel-wurzel, roots and leaves, over five years:—

1.—By superphosphate of lime and potassium sulphate.

2.—By the same mineral manures, with, in addition, ammonium-salts, supplying 7·8 lbs. nitrogen per acre per annum.

3.—The same mineral manures, and ammonium-salts, supplying 86 lbs. nitrogen per acre per annum.

TABLE XI.

MANGEL WURZEL.

Manures and Produce per acre per annum. Five years, 1876-1880.

	Roots.	Leaves.	Total.
	Tons. cwts.	Tons. cwts.	Tons. cwts.
1. Superphosphate of Lime and Potassium Sulphate	4 10	1 0	5 10
2. As 1, and 36½ lbs. Ammonium Salts (= 7·8 lbs. Nitrogen)	6 0	1 6	7 6
3. As 1, and 400 lbs. Ammonium Salts (= 86 lbs. Nitrogen)	14 0	2 16	16 16

Thus, the annual application of 7·8 lbs. of nitrogen has increased the crop by only 30 cwts. of roots per acre per annum; and the

increased yield of nitrogen in the crop was even somewhat less than that supplied in the manure. The application of 86 lbs. of nitrogen, has, however, increased the crop of roots by 160 cwts. more; or by 190 cwts. in all.

It is obvious from these results that the application of the small amount of nitrogen did not enable the plant to take up any from the atmosphere, and that it required a further supply of nitrogen by manure to obtain a further increase of crop.

It is true, as already said, that a small amount of combined nitrogen annually comes down from the atmosphere in rain, and the minor aqueous deposits; but it cannot be doubted that, beyond this, the source of the large amount of nitrogen of root crops is the store of it within the soil, whether this be due to less recent accumulations, or to direct supply by manure. On the other hand, the large amounts of produce obtained by the aid of nitrogenous manures, on plots to which no carbonaceous manure has been applied for about 40 years, is evidence that the atmosphere is at any rate the chief, if not the exclusive source, of the carbon of the crops.

Let us now turn to the question of the actual proportion of leaf to root, and to the distribution of certain constituents in the root and the leaf, respectively.

The results relating to these points will be found in Table XII.

The first line of figures shows that the proportion of leaf to 1000 root ranged from 175 to 243, and that it was the highest with the highest nitrogenous manure, and greatest luxuriance. The proportion of leaf is thus considerably higher than in the case of Swedish turnips, but very much lower than with common turnips. Although each of the various descriptions of root has, so to speak, its own range as to proportion of leaf, yet with the same description there will generally be the more, the heavier the soil, the wetter the season, and the higher the nitrogenous manuring. The proportion will also be higher the less matured the crop at the time of taking up.

Referring now to the percentage composition of the Mangel root and leaf, it is to be observed that whilst with Turnips there was a much higher percentage of solid matter in the leaf than in the root, there is, in Mangels, a considerably higher percentage in the root than in the leaf. The percentage of dry or solid substance in the Mangel root is, in fact, considerably higher than that in the Swedish turnip root, whilst the percentage in the Mangel leaf is much lower than in the Turnip leaf. The question suggests itself, how far this may be due to more complete exhaustion of the leaf in the accumulation of the larger amount of reserve material in the root?

The percentage of nitrogen in the dry substance of the root, is much the higher, the higher the nitrogenous manuring; and it will be seen further on that, beyond comparatively narrow limits, a high percentage of nitrogen may even be a disadvantage, so far as the feeding quality of the root is concerned. As in the case of the Turnips, the percentage of nitrogen is very much higher in the dry substance of

the leaf than in that of the root; and it is as a rule the higher in the leaf the less mature the root.

TABLE XII.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Proportion of leaf to root, and selected constituents in root and leaf, Per cent. and per acre.

Means of Plots 4, 5, and 6. Six years, 1878-1883.

	SERIES 1. No Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
LEAF TO 1000 ROOT.					
	200	183	217	243	175
PER CENT.					
Dry Matter — In root	14·99	12·52	13·70	12·79	13·56
Dry Matter — In leaf	10·43	9·77	10·06	10·10	10·92
Nitrogen in Dry — In root	0·88	1·39	1·25	1·64	1·26
Nitrogen in Dry — In leaf	2·55	2·94	2·86	3·29	2·88
Mineral Matter in Dry — In root	5·48	7·19	6·28	6·91	6·26
Mineral Matter in Dry — In leaf	20·16	19·68	19·66	19·21	18·65
PER ACRE, lbs.					
Dry Matter. — In root...	1504	4665	3823	5444	4691
Dry Matter. — In leaf	210	663	614	1033	667
Dry Matter. — Leaf + or − root	− 1294	− 4002	− 3209	− 4411	− 4024
Nitrogen — In root...	12·9	63·8	45·7	84·7	57·7
Nitrogen — In leaf	5·4	19·5	17·6	34·0	19·2
Nitrogen — Leaf + or − root	− 7·5	− 44·3	− 28·1	− 50·7	− 38·5
Mineral Matter. — In root... ...	81·1	331·3	243·0	379·5	292·1
Mineral Matter. — In leaf	41·4	130·2	119·6	198·0	121·8
Mineral Matter. — Leaf + or − root	− 39·7	− 201·1	− 123·4	− 181·5	− 170·3

It is remarkable that the percentage of mineral matter is about three times as high in the dry substance of the leaf as in that of the root. Further, according to published analyses of the ash of Mangel-root and Mangel-leaf, the ash of the leaf contains a much lower percentage of potash, but about the same percentage of phosphoric acid as that of the root. But owing to the lower percentage of organic

substance in the leaf, and the much higher percentage of ash in the dry substance, the percentage of both potash and phosphoric acid will be much higher in the dry substance of the leaf than in that of the root.

The lower division of the Table XII. (p. 25) shows that the amount of dry or solid substance per acre, in the food-product of the crop, the root, ranges from about $\frac{2}{3}$rds of a ton without nitrogenous manure, to $2\frac{1}{3}$rd tons with the highest nitrogenous manure; and in conjunction with this larger amount there is nearly $\frac{1}{2}$ a ton of dry substance in the leaf.

We have here a striking illustration of how greatly dependent is the amount of carbon assimilated from the atmosphere over a given area, on the amount of nitrogen available to the plant within the soil. The total quantity of dry substance produced by the highest nitrogenous manure was nearly three tons per acre, which would contain considerably more than one ton of carbon; indeed the amount of carbon assimilated in excess of that without nitrogenous manure was not much less than one ton per acre. This is obtained by the leaves from the small proportion of carbonic acid existing in the atmosphere, which does not amount to more than one part of carbon as carbonic acid to 10,000 of air.

The Table further shows that there is five, six, or seven times as much solid matter accumulated in the edible root as in the leaf. Again, notwithstanding the much higher percentage of nitrogen in the dry substance of the leaf than in that of the root, there is, owing to the small proportion of leaf, two, three, or more times as much nitrogen per acre in the root as in the leaf. And again, notwithstanding the very high percentage of mineral matter in the dry substance of the leaf, there is, owing to the small proportion of the leaf, only about half as much total mineral matter per acre in the leaf as in the root. Lastly, so far as can be judged, very much more of the potash of the crop, and much more of the phosphoric acid also, will be in the root than in the leaf.

NITROGEN RECOVERED IN INCREASE OF CROP FOR 100 SUPPLIED IN MANURE.

The next point to consider is—what proportion of the nitrogen of the manure, which is shown to be so effective, is recovered in the increase of the crop of Mangels obtained by its use. Table XIII. gives particulars on this point.

The upper division of the Table shows the amounts of nitrogen supplied by manure per acre per annum to the plots of each of the four series (2, 3, 4, and 5), as already given in the former Tables; those of series 1 receiving no nitrogen.

It should be stated that on the plots of Series 1 with mineral, but without nitrogenous manure, there was obtained in the mangel roots an average of only about 13 lbs. of nitrogen per acre per annum. It should be remembered, however, that the plots yielding these very small amounts of nitrogen, even in the powerfully rooted Mangel crop, have now been under experiment with roots for more than 40 years, during which time they have received no nitrogen whatever by manure.

TABLE XIII.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Nitrogen recovered in Increase of Crop (roots only) for 100 supplied in manure.

Average of 6 years, 1878-'83.

		SERIES 2. Nitrate of Soda.	SERIES 3. Ammonium Salts.	SERIES 4. Ammonium Salts and Rape Cake.	SERIES 5. Rape Cake.
Nitrogen in Manure per acre per annum ...		lbs. 86	lbs. 86	lbs. 184	lbs. 98
NITROGEN RECOVERED IN INCREASE (OF ROOTS ONLY) FOR 100 SUPPLIED IN MANURE.					
3	No Mineral Manure[1]	44·2	23·3	21·1	33·7
5	Superphosphate	57·7	29·7	25·1	38·5
6	Superphosphate and Potassium Sulphate	58·1	44·5	45·5	51·8
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	61·7	40·1	46·4	46·8
	Means of Plots 6 and 4 ...	59·9	42·3	45·9	49·3

[1] Five years only, 1878-'82.

In fact, although in the earlier years the common and Swedish turnip yielded much more, yet in the recent years neither Sugar-beet nor Mangel-wurzel, with their greater powers of accumulation and growth, has removed so much nitrogen without nitrogenous manure as Wheat or Barley grown for between 30 and 40 years in succession on the same land without any artificial nitrogenous supply.

The actual amounts of nitrogen per acre in the roots, when nitrogen was supplied by manure, taking the average of the two mineral manured plots, 6 and 4, where potash was applied, were 64·4 lbs. by the application of 86 lbs. of nitrogen as nitrate of soda, and 49·3 lbs. with the same amount of nitrogen applied as ammonium-salts; thus showing much less effect from a given quantity of nitrogen as ammonium-salts than from an equal quantity as nitrate of soda. This is a general result in the average of seasons, but on the other hand the nitrogen of nitrate of soda is much more liable to loss by drainage, especially in wet seasons. With 98 lbs. of nitrogen in the comparatively slowly available condition as in rape-cake, the average amount in the produce of roots was 61·2 lbs.; and where the rape-cake and the ammonium-salts were used together, raising the supply of nitrogen to 184 lbs. per acre per annum, the average yield of nitrogen in the roots amounted to 97·5 lbs.

Deducting the amounts of nitrogen in the crops without nitrogenous manure, from those where it was supplied, we get the increase due to the supply; and the figures in the Table (XIII.) show, for each plot, and for each series representing the different conditions of supply of nitrogen, the increased amount of nitrogen in the roots for 100 supplied in the manure.

First comparing the four lines of figures with one another, it is seen that, under each condition as to nitrogenous supply, there is much less return for 100 supplied without, than with, the addition of mineral manures. Again, there is, under all conditions of nitrogenous supply, less, and in the cases of the ammonium-salts and the rape-cake very much less, of the supplied nitrogen recovered in the roots where only superphosphate of lime was applied, than where this was used in conjunction with potash, or potash, soda, and magnesia.

Comparing the average results of the two mineral-manured plots where potash was supplied (6 and 4), and nitrogen in the different conditions, as shown in the last line of the Table, it is seen that the amounts of nitrogen recovered as increase in the roots, for 100 supplied in manure, were :—

With Nitrate of soda - - - - - - - -	59·9
With Ammonium-salts- - - - - - - -	42·3
With Rape-cake - - . - - - - . - -	49·3
With Rape-cake and ammonium-salts - -	45·9

Thus, even under the most favourable condition as to mineral supply, frequently less than 50 per cent. of the nitrogen supplied in these artificial manures was recovered in the increase of roots obtained by its use ; and even with the most effective of the nitrogenous manures, the nitrate of soda, only about 60 per cent. was so recovered.

It is obvious that the amount of nitrogen in the roots alone, by no means represents the total quantity assimilated per acre, but as that in the leaves is annually returned to the land as manure, it is clear that, taking the average over a number of years, it is only the amount in the roots that can be credited as immediate return from the manure employed.

Where, however, large amounts of organic matter are returned to the soil, such accumulation serves to keep up the *condition* of the land, so that more or less of the at first unrecovered constituents of the manure will remain for future crops.

Then as to the less return in the roots from a given amount of nitrogen supplied as rape-cake than as nitrate of soda, it should be borne in mind that, although the nitrogen of such organic manures only becomes comparatively slowly available, yet on that account the more remains in the soil as manure-residue for future crops.

Finally, the question obviously suggests itself—what is the result when, instead of these artificial manures, a large amount of nitrogen is supplied in farm-yard manure, which must always be liberally employed if heavy crops of Mangel-wurzel are to be grown ?

In the first place larger quantities of nitrogen would generally be applied per acre in farm-yard manure than in any of the artificial manures used in the experiments which have been described. So far as the results obtained on the farm-yard manure plots enable us to form an estimate, a much smaller proportion of that supplied would be taken up by the immediate crop than in the case of either nitrate of

soda or ammonium-salts, and even less than with rape-cake. But, an essential characteristic of farm-yard manure is, that it leaves a large but only slowly available residue for future crops. It is the nitrogen of the liquid dejections of the animals that is first rendered available within the soil, then that of the finely comminuted matter which passes intermixed with some secretions in the solid excrements, and finally that in the litter. It is, in fact, as already referred to, to the very large proportion of the constituents of the farm-yard manure applied for root-crops, which remains available for future crops, that an important part of the benefit of the growth of root-crops in rotation is to be attributed.

Indeed, it will be clearly seen from the evidence adduced, that the *Root-crops*, which are assumed to perform the office of restoring the condition of the soil for the growth of the crops grown in alternation with them, are themselves pre-eminently dependent on manure for their successful development. In fact, it is only when there is plenty of plant-food available in the soil, whether by accumulation, or direct supply by manure, that good root-crops can be obtained. But, these conditions being fulfilled, these crops, gross feeders as they are, are able to take up a large amount of matter from the soil, and to produce a large amount of vegetable substance; a large portion of which is valuable as food, whilst the remainder is valuable as manure again. Further, of the portion that is used as food for animals, by far the larger proportion of the constituents valuable as manure, is eventually recovered as such in the excrements of the animals.

That is to say, it is the great power of utilising the stores within the soil, due in some cases to accumulation, and in others to direct manuring, which these plants possess, growing and gathering nitrogen as they do after the period of its collection by the cereals, and the fact that it is only a very small proportion of their nitrogen, and of their mineral matter, which is carried off in the increase of the animals and so lost to the land, that constitute a great part of the value of the root crops in rotation. When, however, roots are consumed for the production of milk, the loss to the manure will be greater than when they are consumed by either store or fattening animals. Another very important element in the value of root-crops in rotation is, as already said, the opportunity they afford for the cleaning of the land.

It will be well here briefly to summarise the results which have been adduced, relating to the amounts of produce obtained with the different descriptions of root-crop, under the influence of the different descriptions of manure.

Confining attention in the first place to the produce of the roots per acre, there was, with each description of root, a very considerable increase obtained by the use of nitrogenous manures. The amounts of nitrogen supplied were not the same for each description of plant; but there can be no question that the amount, not only of total vegetable substance produced, but of stock-food yielded, was very much greater

from a given quantity of nitrogen when it was supplied to the Mangels, than when applied to the different descriptions of Turnip. Then, so far as the habit of growth of the different descriptions of plant is concerned, the Swedish Turnip shows the lowest proportion of leaf, the Mangel considerably more, and the common Turnip the most of all.

Having regard to the different characters of growth of the various descriptions of root, it will be of interest to direct attention to the extent to which the different kinds are cultivated in different divisions of the country. Table XIV. gives some information on this point, calculated from the Board of Trade Returns, of the area and produce of various agricultural crops.

TABLE XIV.

ROOT CROPS.

Area under Turnips and Mangels in England and Wales, and in Scotland.

	Mean of 5 years, 1882-1886.			
	Actual area.		Per cent. of Total area.	
	England and Wales.	Scotland.	England and Wales.	Scotland.
	Acres.	Acres.	Per cent.	Per cent.
Turnips (1)	1,531,921	487,810	81·9	99·7
Mangels	337,521	1,432	18·1	0·3
Total	1,869,442	489,242	100·0	100·0

(1) Including Swedes.

It is seen that the average area under the various descriptions of Turnips is, in England and Wales, rather over 1½ million acres; whilst in Scotland it is less than half a million acres. Again, the average area under Mangel-wurzel is 337,521 acres in England and Wales, and only 1,432 acres in Scotland. Further, whilst about 18 per cent. of the total area under roots in England and Wales is devoted to Mangels, less than a third of 1 per cent. of the total root-area in Scotland is devoted to that crop. It may be added that in neither division of the country has either the actual or the relative area fluctuated at all materially during the last ten years. The tendency is, however, to a slight diminution of total area under roots; and especially of Mangels in Scotland.

These facts afford sufficient evidence of the great influence of climate in determining what description of roots should be grown, and that this cannot be settled merely by a consideration of the amount of produce obtained by a given quantity of manure, of the proportion of the crop which is available as food for stock or only remains for manure again, or of the high or low percentage of solid matter in the food portion of the crop.

It has been pointed out that Turnips have a comparatively limited

root-range, and require both a considerable amount, and continuity, of rain, and only moderate temperatures; whilst the deeply and powerfully rooting Mangel is less dependent on continuity of rain after the plant has once got a good start, and will bear, or even requires, a warmer and drier autumn than Turnips.

Thus, whilst it is obviously desirable to extend the growth of the better descriptions of roots as far as possible, judgment must be exercised in the selection, so as to ensure that the kind chosen is suitable to the conditions of the soil and seasons of the locality.

Although Sugar-beet is not grown in this country as food for stock, some attempts have been made to grow it for the manufacture of sugar, or spirit, but hitherto they have failed. There can be little doubt, however, that Sugar-beet of good quality could be grown on favourable soils, and in favourable localities as to season. But it is essential to success that the manufacturer should hold the land, and adapt his rotation and manuring to the crop, and be able to command the quantity of roots he requires, and not be dependent, for both quantity and quality, on farmers in the neighbourhood, as has hitherto been the case, and as has hitherto been a material element in the failures that have occurred. So long, however, as heavy bounties are allowed on the export of beet-root sugar from European countries, a further obstacle stands in the way of the growth of Sugar-beet for the production of sugar in this country.

COMPOSITION OF DIFFERENT DESCRIPTIONS OF ROOTS; AND THEIR VALUE AS FOOD FOR STOCK.

Let us now revert to the question of the composition of the different descriptions of roots. The first points to consider are: the percentages of dry or solid matter, and of nitrogen, in the different roots, and the influence of the conditions of growth on these percentages. Next we have to consider: what are the most important non-nitrogenous food constituents formed in the roots? what is the average proportion of these in the different descriptions of root? and in what direction is the quantity they contain influenced by season and manuring? Lastly, the important question arises, what proportion of the total nitrogenous compounds in the roots is really food material?

First, as to the percentages of dry substance in the different descriptions of root.

Table III. (p. 7), shows that the different series of Norfolk White, or common Turnips, contained 8·54, 8·07, 7·66, and 7·96 per cent., or an average of only about 8 per cent. of solid matter in the roots; and the percentage is the lower the higher the manuring, and the greater the luxuriance, that is the less ripe the roots.

The four-year series of Swedish Turnips (Table V., p. 10) show 11·59, 11·51, 10·54, and 10·89 per cent. dry matter; and the ten-year series (Table VII., p. 14) show 12·04, 11·01, 11·32, 10·94, and 10·83 per cent. The Swedish Turnip shows, therefore, an average of about 11 per cent. of dry matter, or about 3 per cent. more than the Norfolk

White. There is again the lower percentage the higher the manuring, the greater the luxuriance, and the less ripe the roots.

The five series of Mangel-wurzel show (Table XII., p. 25) 14·99, 12·52, 13·70, 12·79, and 13·56 per cent. dry substance, that is a still higher percentage of solid matter than the Swedish Turnip. The average on the most normal plots may be taken at about 13, or about 2 per cent. higher than in the Swedish Turnip. And, as in the other cases, the percentage is directly connected with the condition as to luxuriance on the one hand, or ripeness on the other.

It may be mentioned that in Sugar-beet we found still higher percentages of solid matter, averaging on the more normal plots from 16 to 18 per cent., or from 3 to 5 per cent. higher than in the feeding Mangel. On this point it is of interest to add, that in recent years the most improved varieties cultivated for sugar-making, and grown under the most favourable conditions, contain even still much higher percentages of dry substance. Indeed, sometimes the roots yield as much as 20 per cent. of sugar!

Table XV. shows the average percentages, over four years, of dry matter, mineral matter (ash), nitrogen, and sugar, in the roots of each of the experimental Mangel plots.

The percentages of dry matter are, as already said, quite characteristic. They are much the highest in the roots of Series 1 with no artificial nitrogenous manure, that is with the smallest crops; and they are much the lowest in those of Series 2 and 4, in the one case with the nitrogen supplied in the most active condition, as nitrate of soda, and in the other with the greatest amount of it, indeed an excess, in the manure, and accordingly the greatest luxuriance, the largest crops, and the least matured condition of the roots.

The second division of the Table shows that the mineral matter constitutes nearly 1 per cent. of the roots, so that the amount of organic substance will be nearly 1 per cent. less than that of the total dry or solid matter. Further, there is, as a rule, the more mineral or saline matter, the more luxuriant, the more crude, and the more unripe the roots; and, so far, a relatively high percentage of mineral matter is indication of imperfect maturity and lower feeding value.

Next comes the percentage of nitrogen, the actual amount of which, in the fresh roots, is seen to be very small, but very variable. It is the lower the riper the roots, and it is conversely the higher the greater the luxuriance of growth, and less matured the roots. Indeed it is about one and a half time as high in the case of the largest as in that of the smallest crops; and it will presently be seen that where the amount is relatively high its condition is not so favourable for feeding purposes.

But it is to the lowest division of the Table to which I wish to direct special attention, namely, that showing the percentage of sugar in the roots. The figures show that the percentage of sugar is generally about two thirds that of the total dry or solid matter. In other words, nearly or about two thirds of the solid matter of the feeding Mangel is sugar. It is, indeed, a characteristic of the various descriptions of

TABLE XV.

MANGEL WURZEL.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, on the percentage composition of the Roots.

Average of 4 years, 1877-'80.

		SERIES 1. No Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
	DRY MATTER.—PER CENT.					
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
1	Farmyard Manure	13·6	11·9	12·3	12·0	13·0
2	Ditto and Superphosphate ...	13·3	11·7	12·3	11·6	12·7
3	No Mineral Manure	16·9	13·6	15·6	13·8	14·9
5	Superphosphate	15·0	12·2	14·3	13·2	14·3
6	Superphos. and Potassium Sulphate	15·2	12·3	13·9	13·0	13·5
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride...	14·7	12·1	12·8	11·9	12·3
	Mean of Plots 6 and 4...	15·0	12·2	13·4	12·5	12·9
	MINERAL MATTER (ASH).—PER CENT.					
1	Farmyard Manure	0·958	1·028	1·002	1·016	0·974
2	Ditto and Superphosphate ...	0·951	1·045	1·016	1·031	0·950
3	No Mineral Manure	0·813	0·952	0·820	0·796	0·799
5	Superphosphate	0 791	0·883	0·802	0·754	0·772
6	Superphos. and Potassium Sulphates	0·912	0·975	0·980	0·988	0·908
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride...	0.908	1·016	0·968	1·054	0·974
	Mean of Plots 6 and 4...	0·908	0·996	0·979	1·021	0·939
	NITROGEN.—PER CENT. (AVERAGE 3 YEARS ONLY, 1878-'80).					
1	Farmyard Manure	0·157	0·200	0·190	0·213	0·180
2	Ditto and Superphosphate ...	0·168	0·196	0·192	0·208	0·188
3	No Mineral Manure	0·178	0·218	0·262	0·244	0·215
5	Superphosphate	0·134	0·180	0·182	0·219	0·186
6	Superphos. and Potassium Sulphate	0·142	0·175	0·156	0·212	0·168
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride...	0·121	0·160	0·132	0·168	0·143
	Mean of Plots 6 and 4...	0·132	0·168	0·144	0·190	0·156
	SUGAR.—PER CENT.					
1	Farmyard Manure	8·6	7·1	7·7	7·1	7·8
2	Ditto and Superphosphate ...	8·6	6·9	7·3	7·1	7·8
3	No Mineral Manure	11·4	8·3	9·6	8·7	9·5
5	Superphosphate	10·4	7·5	9·3	8·0	9·4
6	Superphos. and Potassium Sulphate	10·3	7·9	8·9	8·0	8·8
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride...	10·1	7·4	8·5	7·1	8·0
	Mean of Plots 6 and 4...	10·2	7·7	8·7	7·6	8·4

feeding roots that they supply a large amount of the non-nitrogenous, respiratory, and fat-forming substance—*sugar*.

They contain also other non-nitrogenous bodies, such as cellulose, and various pectin compounds, the feeding value of which is not yet satisfactorily determined; but of the importance of the sugar there can be no question.

It is, therefore, obviously of much interest to consider the conditions under which its production is the most favoured. The point is strikingly illustrated in Table XVI., which shows the amounts of sugar yielded per acre under the different conditions as to manuring.

As to the effects of farm-yard manure, which is used so largely for the growth of the feeding beet or Mangel, it is seen that, taking the average of 4 years, considerably more than one ton of sugar per acre is produced by the farm-yard manure alone, and that the amount is increased to more than one and a half ton by the addition to the farm-yard manure of artificial nitrogenous manures.

The quantitative effect of the nitrogenous manures in increasing the amount of sugar produced is, however, more clearly seen in the results with the artificial manures. It must suffice to adduce in illustration the mean results obtained on the two mineral manured plots 6 and 4, of each series; the mineral manure in these cases containing a full supply of potash. These results are given in the bottom line of figures in each of the two main divisions of the Table.

It is seen that there is an average of 1021 lbs. of sugar per acre in the roots of plots 6 and 4 of Series 1, that is without any nitrogenous manure, and that the amount is increased in the other series, where nitrogenous manures are also employed, to 2923, 2653, 3533, and 3063 lbs.

But the effects of the nitrogenous manures are still better discriminated in the figures in the lower main division of the Table, where are given the increased amounts of sugar yielded per acre on the plots with nitrogenous as well as mineral manure, over those on the corresponding plots with the mineral manures alone.

Thus, with 86 lbs. of nitrogen, applied as nitrate of soda, there is an average increase in the produce of sugar per acre on the two plots 6 and 4, of 1902 lbs. With 86 lbs. of nitrogen as ammonium-salts, there is an increase of 1632 lbs. With 98 lbs. as rape-cake, 2042 lbs.; and with 184 lbs. nitrogen as rape-cake and ammonium-salts together, there is an increased production of sugar per acre in the roots of 2512 lbs.

There is obviously the more sugar produced the larger the amount of nitrogen applied as manure, but by no means in proportion to the amount applied. Then, again, the efficiency of a given supply of nitrogen is greatly dependent on the accompanying mineral supply, as is shown by the much less yield of sugar on plot 5, where, with superphosphate of lime annually applied without potash, the potash had become much exhausted.

The bottom line of the Table shows that, taking the mean of plots 6 and 4, each with potash, 1 lb. of nitrogen as nitrate of soda has

yielded 22·1 lbs. of sugar, 1 lb. as ammonium-salts 19·0 lbs. of sugar, 1 lb. of nitrogen in rape-cake 20·8 lbs.; and 1 lb. in rape-cake and ammonium-salts together 13·7 lbs. of sugar. In fact, the greater the excess of nitrogen supplied, the greater the luxuriance, and the less matured the roots, the less is the amount of sugar obtained for a given amount of nitrogen in the manure. It may be added that, with Sugar-beet, much more sugar was obtained for a given amount of nitrogen in manure, than with Mangels.

TABLE XVI.

Mangel Wurzel.

Grown year after year on the same land, Barnfield, Rothamsted.

Results showing the effects of exhaustion and manures, on the amounts of sugar per acre in the roots.

Average of 4 years, 1877-'80.

		SERIES 1. No Artificial Nitrogenous Manure.	SERIES 2. Sodium Nitrate = 86 lbs. Nitrogen.	SERIES 3. Ammonium Salts = 86 lbs. Nitrogen.	SERIES 4. Ammonium Salts and Rape Cake = 184 lbs. Nitrogen.	SERIES 5. Rape Cake = 98 lbs. Nitrogen.
	Sugar Per Acre, lbs.					
1	Farmyard Manure ..	lbs. 2513	lbs. 3109	lbs. 3636	lbs. 3700	lbs. 3433
2	Farmyard Manure and Superphosphate..	2653	3272	3390	3357	3428
3	No Mineral Manure ..	950	2074	1428	1921	2044
5	Superphosphate	1028	2598	1808	2014	2306
6	Superphosphate and Potassium Sulphate	904	2874	2567	3514	3023
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	1137	2971	2739	3552	3103
	Means of 6 and 4 ..	1021	2923	2653	3533	3063
	Increase of Sugar per Acre over Series 1, lbs.					
1	Farmyard Manure ..		596	1123	1187	920
2	Farmyard Manure and Superphosphate..		619	737	704	775
3	No Mineral Manure ..		1124	478	971	1094
5	Superphosphate		1570	780	986	1278
6	Superphosphate and Potassium Sulphate		1970	1663	2610	2119
4	Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride		1834	1602	2415	1966
	Means of 6 and 4 ..		1902	1632	2512	2042
	lbs. Increase of Sugar for 1 lb. Nitrogen in Manure.					
	Means of 6 and 4 ..		22·1	19·0	13·7	20·8

I cannot here discuss the physiological explanations of the fact that nitrogenous manures have such a marked effect on the production of the non-nitrogenous substance—sugar. A direct connection between the supply of nitrogen to the plant, and the formation of non-nitrogenous substances is, however, obvious. It is also obvious, that the effect of a given quantity of nitrogen may be very different, according to the character of the plant, to the mineral supply, and to the climatic conditions.

I will now briefly refer to the more detailed composition of some descriptions of roots, as illustrated by recently published experimental results of others.

Table XVII. gives a summary of results obtained by Dr. Aitken, and published in detail in the *Transactions of the Highland and Agricultural Society of Scotland*, Vol. xvi., 1884. They relate to the composition of Fosterton hybrid Turnips grown in 1882, at the Experimental Stations at Pumpherston and at Harelaw, under various conditions as to manuring. The figures show the mean results of the analyses of 60 differently grown specimens in each case.

TABLE XVII.

Mean of Dr. Aitken's results.

	Roots grown at Pumpherston.	Roots grown at Harelaw.
	Per cent.	Per cent.
Water	91·3	92·6
Dry Matter	8·7	7·4
Per cent. in Dry Matter:—		
Albumen	7·7	7·5
Woody Fibre	10·8	11·7
Ash	5·8	6·4
Carbohydrates, &c.	75·7	74·4
Total	100·0	100·0
AMOUNT AND CONDITION OF THE NITROGEN.		
Per cent. in Dry Matter:—		
As Albuminoids	1·22	
As Non-Albuminoids	0·23	
Total	1·45	
Per cent. of total as Albuminoids	84·1	
Albuminoid ratio	1 to 9·7	

It will be seen that the amount of dry matter averaged 8·7 per cent. in the roots grown at Pumpherston, and only 7·4 per cent. in those grown at Harelaw. It appears that the amount of sugar in the roots was not determined. The figures given in the Table for "carbohydrates, &c." are obtained by deducting the sum of the albumen, woody fibre, and ash, from 100. They include therefore any non-

albuminoid nitrogenous matters, and they are a fraction of 1 per cent. higher than the mean of the individual figures given by Dr. Aitken for "carbohydrates, &c," by which he has calculated the albuminoid ratios, the average of which is given at the foot of the Table. The mean percentage of total nitrogen in the roots is very low, but the proportion of it which is estimated as albuminoid is unusually high.

Table XVIII. gives, in like manner, the mean results of 27 somewhat more detailed analyses of Aberdeen Yellow Turnips, made by Mr. David Wilson, jun. The roots were grown at Carbeth, Killearn, Stirlingshire, by a great variety of manures, and the results are published in the *Transactions of the Highland and Agricultural Society of Scotland*, Vol. xviii., 1886.

TABLE XVIII.

Mean of Mr. David Wilson's results.

	In Fresh Roots.	In Dry Matter.
	Per cent.	Per cent.
Water	91·09	
Sugar	4·72	52·94
Woody Fibre	1·03	11·54
Albuminoids	0·54	6·06
Non-Albuminoid Nitrogen × 6·25	0·60	6·76
Extractive Matter free of Nitrogen	1·36	15·23
Ash	0·66	7·47
Total	100·00	100·00
Amount and Condition of the Nitrogen		
Per cent. in Dry Matter:—		
As Albuminoids		0·970
As Non-Albuminoids		1·086
Total		2·056
Per cent. of total as Albuminoids		47·3
Albuminoid ratio		1 to 12·4

The figures show that the roots contained on the average 91·09 per cent. of water, corresponding to 8·91 per cent. of dry matter. They also show that, of sugar there was an average of 4·72 per cent. in the fresh roots, corresponding to 52·94 per cent. of the total dry substance. The mean percentage of total nitrogen in the dry matter is much higher than in Dr. Aitken's experiments, namely, 2·056; of which only 47·3 per cent. existed as albuminoids. Further, the author reckons that the roots contained 1 part of albumen to 12·4 of "carbohydrates, &c." (including amides).

Table XIX. shows the detailed composition of common Turnips, the results being the mean of the analyses of eleven different specimens, including several different varieties, some grown in different seasons, or by different manures. The roots were grown in 1884 and 1885, on the farm of Canterbury College, New Zealand. The general results

are reported upon by Messrs. W. E. Ivey and G. Gray; and the analyses were made, and are reported upon, by Mr. Gray.

TABLE XIX.

Mean of Mr. G. Gray's results.

	In Fresh Roots.	In Dry Matter.
	Per cent.	Per cent.
Water	90·86	
Sugar	4·87	53·40
Fat, &c.	0·26	2·90
Cellulose	0·90	9·81
Albuminoids	0·37	4·01
Extractive Matters, including Amides, &c.	2·04	22·28
Ash	0·70	7·60
Total	100·00	100·00
Amount and Condition of the Nitrogen.		
Per cent. in Dry Matter:—		
As Albuminoids		0·632
,, Ammonia Salts		0·018
,, Nitrates		0·013
,, Amides, &c.		0·680
Total		1·343
Per cent. of Total Nitrogen:—		
As Albuminoids		47·64
,, Ammonia Salts		1·37
,, Nitrates		0·89
,, Amides, &c.		50·10
Total		100·00
Albuminoid Ratio		1 to 21

It may of course be a question whether the roots would not mature somewhat better, or at any rate differently, in the climate of New Zealand than in our own; but the results are nevertheless of interest, both in themselves, and for comparison with those obtained by others, in other localities.

The figures show that the average percentage of dry matter was a little over 9, and that the average percentage of sugar was 4·87, corresponding to 53·4 per cent. of the total dry substance of the roots. Some other of the results will be referred to presently.

The next point to consider is the amount, and the condition, of the nitrogen in Roots of different descriptions, or grown under different conditions.

In perfectly ripened seeds, by far the larger proportion of the nitrogen exists as albuminoids; in fact, in many cases nearly the whole of the nitrogen is in that form. In ripened products, however, some, and in unripened ones sometimes a large proportion, of the nitrogen

exists as amides. Now, so far as present knowledge goes, it is only the nitrogen existing in food as albuminoid compounds, that can contribute to the formation of the nitrogenous compounds of animal bodies, or of milk. It would seem not improbable, however, that some amide compounds may replace the albuminoids in supplying material for the transformations incident to the constant waste of the nitrogenous substances of the body, the products of which pass from it in the urine.

Then, again, besides albuminoids and amides, succulent or immature vegetable substances may contain nitrogen as nitric acid, or as ammonia, unchanged from the condition in which it has been taken up by the roots of the plant from the soil, or the one transformed into the other.

The question as to the condition of the nitrogen in vegetable food, and especially in such crude and immature products as our feeding roots, is, therefore, one of great importance to consider. In the early reports of Rothamsted feeding experiments, published from 35 to 40 years ago, we called attention to the fallacy of estimating the whole of the nitrogen of our stock-foods as protein or albuminoid compounds, especially in the case of succulent and unripened products.

Table XX. gives results as to the condition of the nitrogen, in the experimental rotation Swedes grown at Rothamsted in 1880, and in the experimental Mangels, grown in 1878, 1879, and 1880.

It will be remembered that one portion of the rotation land had been entirely unmanured throughout 10 courses of four years each, and that the roots so grown were quite abnormal; none of the characters of the cultivated root being developed under these circumstances. The results given in the Table (XX.) relate to the roots grown in 1880, which constituted the first crop of the ninth course. It is seen that with a very high percentage of total nitrogen in the roots (0·347 in the fresh, and 2·758 in the dry), they also contained a high percentage of albuminoid nitrogen, which corresponded, however, to only 32·9 per cent. of the total nitrogen.

The next plot has, through the same 10 courses, received no nitrogenous manure whatever. For each of the first nine courses it received superphosphate of lime alone, but for the tenth course, salts of potash, soda, and magnesia, in addition. Under these conditions the roots of the ninth course show a very low percentage of nitrogen in their dry substance (0·888), but 55·8 per cent. of it existed as albuminoid compounds.

Lastly, the third plot received, each course, a complex manure, both mineral and nitrogenous. The percentage of total nitrogen in the dry substance of the roots (1·539), though not high, was nevertheless nearly twice as high as in the case of the roots grown by superphosphate alone; and the proportion of the nitrogen which was as albuminoids, was only 40·1 per cent.

Then again, it is seen that in the cultivated roots by far the larger proportion of the albuminoid nitrogen existed in the juice, that is to say was soluble; whilst in the unmanured or, so to speak, uncultivated roots, a comparatively small proportion of the total albuminoids existed in the juice.

TABLE XX.

Showing the condition of the Nitrogen in Swedish Turnips, and in Mangel Wurzel.

	Total Nitrogen.		Albuminoid Nitrogen.		Per cent. of the Total Nitrogen.						
					As Albuminoids.			As Amides.	As Nitric Acid.	Other forms.	Total.
	In fresh Roots.	In dry matter.	In fresh Roots.	In dry matter.	In Marc.	In Juice.	Total.				
ROTATION SWEDES. Season 1880.											
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	
Unmanured	0·347	2·758	0·114	0·906	21·1	11·8	32·9	?	?	67·1	100
Superphosphate	0·108	0·888	0·060	0·495	20·4	35·4	55·8	?	?	44·2	100
Mixed Manure	0·171	1·539	0·066	0·595	14·6	25·5	40·1	?	?	59·9	100
MANGEL WURZEL. 1878. (Mineral Manures and Rape Cake.)											
Superphosphate	0·211	1·520	0·065	0·590	7·6	23·0	30·6	?	?	69·4	100
Superphosphate and Potassium Sulphate	0·197	1·618	0·057	0·578	10·7	18·3	29·0	?	?	71·0	100
Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	0·171	1·525	0·035	0·390	1·8(*)	18·7	20·5	?	?	79·5	100
MANGEL WURZEL. 1879. (Mineral Manures and Rape Cake.)											
Superphosphate	0·182	1·166	0·071	0·562	17·0	21·7	38·7	?	4·2	57·1	100
Superphosphate and Potassium Sulphate	0·157	1·087	0·065	0·560	19·1	22·1	41·2	?	11·1	47·7	100
Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	0·136	1·010	0·055	0·506	15·3	24·8	40·1	?	14·2	45·7	100
MANGEL WURZEL. 1880. (Mineral Manures and Rape Cake.)											
Superphosphate	0·165	1·344	0·059	0·613	13·4	22·7	36·1	43·8	12·0	8·1	100
Superphosphate and Potassium Sulphate	0·151	1·145	0·067	0·628	18·5	25·7	44·2	41·9	?	13·9	100
Superphos., Pot., and Magnesium Sulphates, and Sodium Chloride	0·123	1·099	0·051	0·564	16·8	25·0	41·3	41·8	11·7	5·2	100

(*) Probably too low.

These results with Swedish Turnips are very instructive, as showing how very dependent is the proportion of the nitrogen existing in the favourable food condition of albuminoid compounds, on the conditions of the manuring, and on the maturity of the crop.

In the results relating to the Mangels the influence of season as well as of manure, on the condition of the nitrogen, is illustrated.

Three plots were selected for investigation, which, with pretty full amounts of produce, would give roots of fairly good degree of maturation, namely, those manured with rape-cake in addition to various mineral manures.

In 1878 there were somewhat under-average crops, with a large proportion of leaf, conditions indicative of comparative immaturity. Under these circumstances, the percentage of total nitrogen in the roots was not high, but the proportion of the total nitrogen existing as albuminoids was low, namely 30·6 and 29·0 per cent. in two cases, and only 20·5 per cent. in the third, but in this last case it was concluded that the determination was too low.

In the very wet and cold season of 1879 the crops were very small, and the percentage of total nitrogen was low, the result being, doubtless, partly due to loss of nitrogen by drainage. Under these circumstances the amounts of the total nitrogen found as albuminoids were 38·7, 41·2, and 40·1 per cent., or an average of about 40 per cent.

In 1880 the crops were much above the average, and the percentage of total nitrogen was low; and there is again, under the better conditions as to mineral manuring, that is where potash was applied, more than 40 per cent. of the total nitrogen albuminoid.

As in the case of the manured Swedes, so in every case with the Mangels, the greater part of the albuminoid nitrogen is in the juice, that is to say it is soluble.

The bottom division of the Table shows that in the crops of 1880, in which alone the amides were determined, the proportion of the nitrogen in that condition was, in each case, somewhat over 40 per cent. of the total nitrogen, or approximately the same as that of the albuminoid nitrogen. Table XIX. (p. 38), which gives the average composition of the eleven New Zealand specimens of common Turnips, shows that the proportion of the nitrogen reckoned as "amides, &c.," was 50·1 per cent. of the total nitrogen; that is, rather more than was found as albuminoids in the same roots, and more than was found as amides in the Rothamsted Mangels.

In all three cases in 1879, and in two in 1880, the amount of the nitrogen existing as nitric acid was also determined. It is seen that, with one exception, in which the nitrogen as nitric acid amounted to only 4·2 per cent. of the total nitrogen, it ranged from 11 to 14 per cent. of the total. Compared with these amounts, the results given in Table XIX. show less than 1 per cent. of the total nitrogen of the common turnips to exist as nitric acid, and not much more than 1 per cent. as ammonia. It may be added that in some determinations made at Rothamsted in Swedes, the proportion of the total nitrogen as nitric acid was very much less than in the Mangels.

The results of Dr. Aitken, with Fosterton Hybrid Turnips, show in no case less than 70, in several over 90, and an average of 84·1 per cent. of the total nitrogen as albuminoids; that is about twice as much as was, in most cases, found at Rothamsted in Swedish Turnips and Mangel Wurzel. The results of Mr. David Wilson, with Aberdeen Yellow Turnips, show a range from 32·0 to 62·9, and an average of 47·3 per cent. of the total nitrogen to be albuminoid. Lastly, those of Mr. G. Gray, with the eleven different specimens of common Turnips grown in New Zealand, show a range from 29·94 to 61·01, and an average of 47·64 of the total nitrogen to be albuminoid.

Thus the results obtained with common Turnips by Mr. David Wilson and by Mr. G. Gray, agree in showing an average of less than 50 per cent. of the total nitrogen to exist as albuminoids; and their results are, so far, fairly accordant with those obtained at Rothamsted with Swedes. The results of Dr. Aitken, on the other hand, show, with Fosterton Hybrid Turnips, grown at Pumpherston, an average of 84 per cent. of the total nitrogen to be albuminoid. It is, indeed, well known that Turnips grown in certain localities on the East of Scotland have, weight for weight, a much higher feeding value than those grown in the West of Scotland, or in England. But it is certainly very remarkable that any such products as succulent Roots should contain as high a proportion of their total nitrogen in the albuminoid condition as might be found in imperfectly ripened grain.

If the result be real, and neither it nor the season were exceptional, the question suggests itself whether the quality of feeding roots may not be improved in this direction, as well as in that of increased yield of sugar, by the careful selection of plants from which to grow seed, as has been done with such marvellous success in the case of Sugar-beet with a view to an increased production of sugar. At the same time, the results which have been adduced afford abundant evidence that roots grown from the same seed will vary very greatly, both as to their percentage of sugar, and as to the amount and the condition of their nitrogen, according to the conditions of growth, and to the maturity of the crop.

SUMMARY AS TO THE COMPOSITION, AND THE FEEDING QUALITIES, OF ROOTS.

So far as the evidence at command enables us to judge, there is in Mangels, with their more extended root-range, greater power of accumulation, more luxuriant growth, and frequent greater immaturity when taken up, a somewhat less proportion of the total nitrogen in the albuminoid condition than in either common Turnips or Swedes. There is also, probably, a less proportion of amide nitrogen, and pretty certainly a larger proportion of nitrogen as nitric acid, and in other forms.

It has been shown that root-crops, as grown for stock-food, are essentially *sugar crops*.

The results obtained by Mr. David Wilson, with Aberdeen Yellow

Turnips, show an average of 8·91 per cent. of dry matter, and of 4·72 per cent. of sugar, in the fresh roots, corresponding to 52·94 per cent. of sugar in the dry substance of the roots.

The eleven specimens of Turnips, grown in New Zealand, show an average of 9·14 per cent. of dry matter, and 4·87 per cent. of sugar, in the fresh roots, corresponding to 53·4 per cent. of sugar in the dry matter.

In Johnston's *Elements of Agricultural Chemistry and Geology*, by Cameron, the following estimates of the average percentages of dry matter, and of sugar, in various descriptions of roots, are given :—

	White Turnips.	Yellow Turnips.	Swedish Turnips.	Mangel Wurzel.
	Per cent.	Per cent.	Per cent.	Per cent.
Dry Matter ..	8·00	9·44	10·54	12·00
Sugar	3·00	3·90	4·60	5·60

These percentages of sugar in the fresh roots correspond, respectively, to 37·5, 41·3, 43·6, and 46·7 per cent. in the dry substance.

In a lecture delivered in February, 1886, before the Kingscote Agricultural Association, Dr. Voelcker gives the following estimates of the average amounts of dry matter, and of sugar, in various roots :—

	Turnips.	Swedes.	Mangels.
	Per cent.	Per cent.	Per cent.
Dry Matter	8·5	10·5	11·5
Sugar	3·0	5·0	5·5

These amounts of sugar in the fresh roots correspond to 35·3 per cent. in the dry substance of the turnips, to 47·6 per cent. in that of the swedes, and to 47·8 per cent. in that of the mangels.

The amounts of sugar found in the experimental rotation Swedes grown at Rothamsted in 1880 were :—

	In fresh Roots.	In Dry Matter.
	Per cent.	Per cent.
Without Manure	6·26	49·75
With Superphosphate	7·69	63·42
With Mixed Manure, including Nitrogen	6·30	56·77

Table XV. (p. 33) shows that in Mangels grown with rape-cake and mineral manures, the average percentage of sugar over four years, ranged, according to the mineral manure, from 8·0 to 9·4 per cent. in the fresh roots, corresponding (with different percentages of dry matter in the two cases) to 65·0 and 65·7 per cent. in the dry substance.

The various results adduced clearly show, not only that the various descriptions of Roots differ much in composition one from another, but that the composition of one and the same description will vary very greatly, according to the conditions of growth, and of the maturity of

the Roots accordingly. It will nevertheless be useful to give such an estimate as the evidence at command permits, of the approximate average percentages of dry matter, and of sugar, in different descriptions of feeding roots.

TABLE XXI.

Estimates of the approximate average percentages of dry matter, and of sugar, in different descriptions of roots.

	Dry Matter	Sugar per cent.	
		In Fresh Roots.	In Dry Matter.
	Per cent.	Per cent.	Per cent.
White Turnips	8·0	3·5 to 4·5	44 to 56
Yellow Turnips..	9·0	4·0 to 5·0	44 to 56
Swedish Turnips	11·0	6·0 to 7·0	55 to 64
Mangel Wurzel	12·5	7·5 to 8·5	60 to 68

Thus, then, even in common Turnips, one half or more of the total solid matter of the roots may be sugar. Of the total dry matter of Swedish Turnips a larger proportion, and of that of Mangels a larger proportion still, will be sugar; indeed, in well-matured Mangels, about two-thirds of the total solid matter may be sugar.

Now, it may be stated that, in the cereal grains, the proportion of albuminoid matter to the non-nitrogenous food material (starch, &c.) is about as 1 to 6 (more or less); and that this is a proportion which may be said to be as a rule fairly favourable for the requirements of fattening animals.

According to the results and calculations of Dr. Aitken, the albuminoid ratio, that is the ratio of the "carbohydrates, &c.," to 1 of albumen, ranged from 7·6 to 12·2, and averaged about 10, in the sixty specimens of Fosterton Hybrid Turnips grown at Pumpherston. Mr. David Wilson's results, with Aberdeen Yellow Turnips, show a range from 6·5 to 16·4, and an average of 12·4 "carbohydrates, &c." (including amides, &c.) to 1 of albumen. According to the calculations of Mr. G. Gray, in the eleven specimens of common Turnips grown in New Zealand, the albuminoid ratio ranged from 1 to 16 to 1 to 31; and it averaged about 1 to 21. It would appear that, in none of these various estimates is any of the woody fibre estimated as digestible, though it is probable that some of it would be so when consumed by ruminants. On the other hand, in the calculations of Mr. David Wilson and Mr. G. Gray, the non-albuminoid nitrogenous compounds are included with the carbohydrates, &c.; but Dr. Aitken's figures do not clearly show whether or not he has so included them.

The estimates are, therefore, obviously only approximations to the truth; but the results are nevertheless of much significance and importance, in showing how comparatively very low is the proportion of albuminoid to digestible non-nitrogenous matter in common Turnips. In the case of other roots, such as Swedish Turnips and Mangels, it is probable that, owing to the greater proportion of sugar which they

contain, the ratio of the albuminoid to the non-nitrogenous matters will, as a rule, be lower still.

It is obviously very essential to give with Roots other foods which are richer in albuminoid substances, and which contain a higher proportion of albuminoid to digestible non-nitrogenous substances. Nevertheless, Roots are, by virtue of the amount of sugar they supply, very valuable for meeting the respiratory requirements of the animals, and also for fat-forming, and for milk production, when given in due admixture.

In conclusion, from all the illustrations that have been adduced, it will be obvious that both the quantity and quality of the produce, and consequently its feeding value, will greatly depend on the selection of the best description of Roots to be grown, and on the character and the amount of the manure, and especially on the amount of nitrogenous manure, to be employed. It will at the same time be obvious, that no hard and fast lines can be laid down in regard to these points. Independently of the necessary consideration of the general economy of the farm, the choice must be influenced partly by the character of the soil, but very much more by that of the climate. Judgment, founded it is true on knowledge, and aided by careful observation, both in the field and in the feeding shed, must be relied upon as the guide of the practical farmer.

GENERAL SUMMARY, AND CONCLUSIONS.

1. Like Sugar-beet grown for sugar, Roots grown for feeding purposes, are very artificial productions. The swollen root consists of a very abnormal development of the reserve material for the second growth of stem and seed; and the conditions of growth, as to the period of the season selected, the soil, and the manuring, are such as to obtain the maximum development within the season.

2. Roots, as grown in our rotations, are generally considered to be restorative crops. But they depend for their successful development on large quantities of manure; which is sometimes applied for the previous grain crop, but more frequently directly for the Roots themselves; and when grown without manure, even from the same seed as the manured crop, either for a few years in succession on the same land, or even in rotation, they soon revert to the uncultivated condition.

3. Independently of the great advantage arising from the opportunity which the growth of Roots affords for the cleaning of the land, the benefits of growing the crop in rotation are due—to the large amount of manure applied for its growth, to the large residue of the manure left in the soil for future crops, to the large amount of matter at once returned as manure again in the leaves, to the large amount of food produced, and to the small amount of the most important manurial constituents of the roots which is retained by the animals consuming them, the rest returning as manure again.

4. It is entirely fallacious to suppose that Root-crops gain a large amount of nitrogen from atmospheric sources by means of their extended leaf-surface. No crop is more dependent on nitrogen in an available condition within the soil; and if a good crop of Turnips is grown by superphosphate of lime alone, it is a proof that the soil contained the necessary nitrogen. In fact, provided the season be favourable, the *condition* of land, so far as nitrogen is concerned, may be more rapidly exhausted by the growth of Turnips by superphosphate than by any other crop.

5. A characteristic difference between the uncultivated and the cultivated Turnip root is, that the cultivated root contains a much lower percentage of nitrogen, and a much higher percentage of non-nitrogenous constituents, especially sugar, by the accumulation of which the percentage of nitrogen is reduced. Yet it is under the influence of nitrogenous manures that the greatest amount of the non-nitrogenous substance—sugar—is produced.

6. If nitrogenous manures are used in excess, that is in such amount as so to force luxuriance that the roots do not properly mature within the season, there will be, not only a restricted production of root, but an undue amount and proportion of leaf. In fact, the higher the nitrogenous manuring, and the heavier the soil, the greater is the tendency to produce a large amount of leaf.

7. In the case of both common and Swedish Turnips, the leaf contains a much higher percentage of dry substance than the root; and the dry substance of the leaf contains a much higher percentage of both nitrogen and total mineral matter than does that of the root.

8. Common Turnips yield a much higher proportion of leaf to root than Swedish Turnips; and if the leaf be unduly developed, there may even be more nitrogen, and more total mineral matter, remaining in the leaf to serve only as manure again, than accumulated in the root to be used as food. In the case of Swedish Turnips, however, not only is the proportion of leaf to root very much less under equal conditions of growth, but the amount of dry matter, of nitrogen, and of mineral matter, remaining in the leaf, is very much less than in the root. In fact, whilst in the case of common Turnips a very large amount of the matter grown is accumulated in the leaf and only serves as manure again, in that of Swedish Turnips a comparatively small proportion of the produce is useless as food for stock.

9. The root of the Swedish Turnip contains a less percentage of water, that is a higher percentage of solid matter or food-material, than that of the common Turnip. The dry or solid matter of the Swedish Turnip root also contains a lower percentage of mineral matter, and consequently a higher proportion of organic food-substance.

10. The more deeply and powerfully rooting, and more vigorous Mangel, is sown earlier, has a longer cycle of growth, and even under the same conditions as to manuring, yields more produce per acre than

either common or Swedish Turnips. It requires, however, for full crops, much heavier dressings of manure.

11. The proportion of Mangel leaf to root is, as a rule, very much less than in the case of common Turnips, but more than in that of Swedish Turnips.

12. With the more extended root range of the Mangel, it is less dependent on continuity of rain when growth is once well established; and it bears, or rather requires, for its full development, a higher temperature than the Turnip.

13. The Mangel root contains a higher percentage of solid matter than either common or Swedish Turnips. But whilst the Turnip leaf contains a much higher percentage of dry matter than the Turnip root, the Mangel leaf contains a much lower percentage of dry matter than the Mangel root; and also a very much lower percentage than the Turnip leaf.

14. As in the case of Turnips, the dry substance of the Mangel leaf contains a much higher percentage of both nitrogen and mineral matter than does the dry substance of the root. Indeed the dry substance of the Mangel leaf contains not far from twice as high a percentage of mineral matter as that of the Turnip leaf; but it contains upon the whole a rather lower percentage of nitrogen than that of the Turnip leaf. It would seem that the Mangel leaf is more fully exhausted of migratory organic matters in the greater development of the root, than is the Swede leaf, and more still than the common Turnip leaf.

15. Superphosphate is much less beneficial to Mangels than to Turnips. In mangels, as in Turnips, the amount of dry substance grown has a very direct relation to the amount of nitrogen available within the soil. But more vegetable substance was produced, and more stock-food yielded, from a given quantity of nitrogen applied to Mangels, than to either description of Turnips. By the application of nitrogen to the soil for Mangels, there was, in many cases, an increased assimilation of about a ton of carbon per acre from the atmosphere.

16. Taking the average of six years, the amount of nitrogen recovered in the increased crop of Mangel roots was about 60 per cent. of that supplied when nitrate of soda was used, about 42 per cent. when ammonium-salts, about 50 per cent. when rape cake, and about 46 per cent. when an excessive amount in a mixture of rape cake and ammonium-salts was employed. There was, of course, an additional amount accumulated in the leaves, but these were annually returned to the soil as manure.

17. When farmyard manure is applied for Mangels, larger amounts of nitrogen are supplied per acre than were used in any of the Rothamsted experiments with artificial manures, a less proportion of the nitrogen supplied is recovered in the increase of crop, and more remains for

future crops. It is the nitrogen of the liquid dejections of the animals that is first rendered available within the soil, then that of the finely comminuted matter mixed with some secretions in the solid excrements, and finally that of the litter.

18. As in the case of Turnips, these assumed restorative crops are themselves pre-eminently dependent on manure for their development. They produce a large amount of vegetable substance, but a large amount of the manure remains for future crops; whilst, of the substance grown, that accumulated in the leaf is at once manure again, and of the portion used as food by far the larger proportion of the constituents valuable as manure is eventually recovered as such in the excrements of the animals. When, however, the roots are consumed for the production of milk, the loss to the manure will be greater than when they are consumed by either store or fattening stock.

19. The selection of the proper description of Roots to be grown cannot be settled merely by a consideration of the amount of produce obtained from a given quantity of manure, of the proportion of the crop which is available as food for stock or only remains for manure again, or of the high or low percentage of solid matter in the food portion of the crop. The general economy of the farm, the character of the soil, but more especially that of the climate of the locality, must also be taken into account. The great influence of climate is strikingly illustrated by the different proportions in which the different descriptions of Roots are grown in different divisions of the United Kingdom.

20. The experiments showed a higher percentage of dry matter in Swedish than in common Turnips, and a higher percentage in Mangels than in Swedes. But, with each description of Roots, the range in the percentage was considerable, according to season and to manuring. The percentage of dry matter was the lower, the greater the excess of nitrogenous manure, the greater the luxuriance, the larger the crops, and the less matured the roots; and it was, conversely, the higher the more matured the Roots.

21. The percentage of mineral matter in the Roots was the higher, the greater the luxuriance, and the more crude and unripe the Roots.

22. The percentage of nitrogen in the Roots was very small, but very variable. It was the higher the more nitrogen was applied by manure, the greater the luxuriance, and the less matured the Roots; and it was the lower the riper the Roots.

23. Nearly two-thirds of the dry substance of Mangels was found to be sugar. The *percentage* of sugar was the greater the more mature the Roots; and it was consequently the greater in the Roots of the smaller crops. But the amount of sugar *per acre* was much the greatest with the largest crops; that is where the most nitrogen was applied in the manure. The Roots grown by farmyard manure alone contained more than one ton of sugar per acre; and by the addition of artificial nitrogenous manure to the farmyard manure, there was an

increase of more than half a ton of sugar per acre. In several cases the addition of artificial nitrogenous to a complete mineral manure, increased the production of sugar by more than a ton per acre.

24. By the addition of nitrogenous to a complete mineral manure, 1 lb. of nitrogen applied as nitrate of soda yielded an increase of 22·1 lbs. of sugar; 1 lb. nitrogen as ammonium-salts 19 lbs. of sugar; 1 lb. as rape cake 20·8 lbs. of sugar; and 1 lb. of nitrogen applied in excessive amount in a mixture of rape cake and ammonium-salts gave an increase of only 13·7 lbs. of sugar.

25. In ripened products by far the larger proportion of the nitrogen exists in the most favourable food-condition of albuminoids, or protein compounds; but in unripened ones, and especially in such succulent, crude, and immature productions, as feeding roots, a large portion of the nitrogen exists in the much less valuable condition of amide-compounds, and in some cases a not inconsiderable amount is in the non-food, or even injurious forms, of nitrates and ammonium salts.

26. In Mangels, with their more luxuriant growth, and frequent greater immaturity when taken up, there is probably, as a rule, a less proportion of the total nitrogen in the albuminoid condition than in either common Turnips or Swedes. There is also probably a less proportion of amide nitrogen, and pretty certainly a larger proportion of nitrogen as nitrates and in other forms. But the range in the proportion of the nitrogen as albuminoids varies very much with each description of roots, being the less the greater the luxuriance, and the less matured the crop.

27. Feeding roots are essentially *sugar crops*. Although the percentage of dry matter varies considerably with each description of Root, according to the conditions of growth, the average amount of dry matter may be taken as, approximately, 8 per cent. in white Turnips, 9 per cent. in yellow Turnips, 11 per cent. in Swedes, and 12·5 per cent. in Mangels. Of the dry matter of white and yellow Turnips nearly, or more than half, may be sugar; of that of Swedes more than half; and of that of Mangels nearly, or as much as, two-thirds may be sugar.

28. In cereal grains, the proportion of albuminoid matter to non-nitrogenous food-material is about as 1 to 6. In roots the albuminoid ratio varies very greatly; but it is probably seldom more than 1 to 12, and frequently as low as 1 to 20 or more. The ratio will probably, as a rule, be lower in Swedes than in common Turnips, and lower still in Mangels.

29. With Roots, should be given other foods, richer in albuminoid matters, and which contain a higher proportion of albuminoid to digestible non-nitrogenous substances; but they are, by virtue of the large amount of sugar they supply, very valuable for meeting the respiratory requirements of the animals, also for fat-forming, and for milk-production.

30. Both the quantity and the quality of feeding Roots, and consequently the feeding value of the crop, depend greatly on the description grown, and on the character and amount of the manure, and especially on the amount of nitrogenous manure, employed. Independently of the necessary consideration of the general economy of the farm, the choice on these points must be guided, partly by the character of the soil, but very much more by that of the climate of the locality.

G. H. HARMER, PRINTER, WILTS AND GLOUCESTERSHIRE STANDARD OFFICE, CIRENCESTER.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,

ON THE

GROWTH OF POTATOES,

FOR TWELVE YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

A LECTURE DELIVERED JULY 27, 1888,

AT THE

ROYAL AGRICULTURAL COLLEGE,

CIRENCESTER,

BY

J. H. GILBERT, M.A., LL.D., F.R.S.,

SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD,

AND

HONORARY PROFESSOR OF THE COLLEGE.

FROM THE "AGRICULTURAL STUDENTS' GAZETTE."
NEW SERIES.—VOL. IV., PART II.

RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF POTATOES, FOR TWELVE YEARS IN SUCCESSION ON THE SAME LAND.

TABLE OF CONTENTS.

	PAGE
INTRODUCTION	1
PRODUCE WITHOUT MANURE, AND WITH VARIOUS ARTIFICIAL MANURES (Table I., p. 3)	2
PRODUCE WITHOUT MANURE, AND WITH FARM-YARD MANURE (Table II., p. 7)	6
CONSTITUENTS IN THE CROPS PER ACRE PER ANNUM :—	9
1. ARTIFICIAL MANURE SERIES (Table III., p. 10)	9
2. FARM-YARD MANURE SERIES (Table IV., p. 14)	13
INFLUENCE OF SEASON AND MANURING ON THE PERCENTAGE COMPOSITION OF THE TUBERS :—	17
1. ARTIFICIAL MANURE SERIES (Table V., p. 18)	19
2. FARMYARD MANURE SERIES (Table VI., p. 21)	21
COMPOSITION OF THE WHOLE TUBERS, AND OF THE JUICE (Table VII., p. 23)	22
CONDITIONS OF COMBINATION OF THE NITROGEN OF THE POTATO ; AND THE DISTRIBUTION OF THE NITROGENOUS CONSTITUENTS, IN THE SOLID MATTER, AND IN THE JUICE (Table VIII., p. 26)	25
DISTRIBUTION OF CONSTITUENTS IN 1000 PARTS OF FRESH TUBERS (Table IX., p. 28)	27
INCREASED PRODUCTION OF STARCH BY NITROGENOUS MANURES (Table X., p. 31)	30
CONDITIONS OF SEASON AND MANURING FAVOURING DISEASE	33
CHEMICAL CHANGES IN THE TUBERS INDUCED BY THE DISEASE (Table XI., p. 36)	34
FURTHER EVIDENCE AS TO THE CHANGES INDUCED BY THE DISEASE (Table XII., p. 39)	38
SUMMARY	41
YIELD OF POTATOES IN DIFFERENT COUNTRIES (Table XIII., p. 43, and Table XIV., p. 44)	42

INTRODUCTION.

My lecture here last year was devoted to the consideration of the conditions and the results of growth of the pre-eminently sugar-yielding root-crops, and I have now to direct your attention to the conditions and the results of growth of the pre-eminently starch-yielding Potato.

From the point of view of the vegetable physiologist the Potato is not a root, but a tuber ; but from the point of view of the agriculturist it might well be classed as a root-crop.

It does not fall within my scheme of illustration, to discuss at any length the history of the Potato as a European crop. It will suffice to say that it seems to have been introduced into this country from Virginia, just about three centuries ago ; though it is probable that it had been introduced into Portugal, and thence into other continental countries, some years earlier.

It is also outside of my plan to enter into a consideration of the comparative characters of the enormous number of varieties now cultivated ; or of the differences in the treatment of the crop, according to soil, climate, and other local circumstances.

My special object is to show the general requirements of the crop, both actually, and as compared with other crops, and the actual and comparative characters and composition of the product obtained.

As in my lectures on other crops, I propose to draw my illustrations, mainly from the results of Field experiments on the growth of the Potato by different manures, for a number of years in succession on the same land, at Rothamsted, and from those of collateral investigations into the composition of the produce, made in the Rothamsted Laboratory. I shall, however, bring to my aid the results of other investigators, so far as the subject may require, and my limits as to time and space will permit.

PRODUCE WITHOUT MANURE, AND WITH VARIOUS ARTIFICIAL MANURES.

First as to the average produce of Potatoes, per acre, per annum, without manure, and with different descriptions of manure.

Table I. (p. 3), shows the results obtained without manure, and by six different descriptions of artificial manure; and Table II. (p. 7), shows the results without manure, and with farm-yard manure, either alone, or with other manures.

In each case, the particulars given are, the average annual amounts obtained per acre, of good, of small, and of diseased Potatoes, the total amount of tubers, and the percentage of diseased in the total produce. In the case of the artificial manure series, these particulars are given, for the first four, the second four, the third four, and the total period of twelve years, of the continuous growth of the crop on the same land; and in the case of the farm-yard manure series, the results are given for six, six, and twelve years.

The artificial manure series comprises the following conditions as to manuring:—

1. Without manure.
2. Superphosphate of lime alone.
3. A "mixed mineral manure," containing superphosphate, and salts of potash, soda, and magnesia.
4. Ammonium-salts alone, supplying 86 lbs. of nitrogen, per acre per annum.
5. Nitrate of soda alone, also supplying 86 lbs. of nitrogen, per acre per annum.
6. The ammonium-salts, and the "mixed mineral manure" together.
7. The nitrate of soda, and the "mixed mineral manure" together.

It should be added, that the description of Potatoes grown during the first four years was the "Rock," but subsequently the "Champion."

The last column but one of Table I. shows that, without manure, with ammonium salts alone, and with nitrate of soda alone, the average produce of tubers was less over each succeeding period of four years. On the other hand, with the superphosphate alone, with the mixed

TABLE I.
POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Manures and Produce per acre per annum; 12 years, 1876-1887.

	Good,		Small.		Diseased.		Total.		Per cent. Diseased in Total.
UNMANURED. (Plot 1.)									
	Tons.	cwts.	Tons.	cwts.	Tons.	cwts.	Tons.	cwts.	Per cent.
Averages 4 years, 1876-1879	2	3½	0	6⅛	0	2¼	2	12¼	5·14
Averages 4 years, 1880-1883	1	12¼	0	4⅛	0	0⅝	1	18¼	1·63
Averages 4 years, 1884-1887	1	3⅝	0	4	0	0⅜	1	8	1·43
12 years, 1876-1887	1	13½	0	5	0	1¼	1	19¾	3·15
SUPERPHOSPHATE OF LIME. (Plot 9.)									
Averages 4 years, 1876-1879	2	18⅜	0	8⅜	0	4⅞	3	11⅞	6·89
Averages 4 years, 1880-1883	4	9⅜	0	5	0	2⅛	4	16¼	2·16
Averages 4 years, 1884-1887	2	7⅛	0	3⅜	0	1	2	11¾	1·98
12 years, 1876-1887	3	5	0	5⅜	0	2¼	3	13⅜	3·66
MIXED MINERAL MANURE. (Plot 10.)									
Averages 4 years, 1876-1879	3	3½	0	6½	0	5¼	3	15½	6·90
Averages 4 years, 1880-1883	4	9⅞	0	4½	0	1⅛	4	16	1·64
Averages 4 years, 1884-1887	2	9¼	0	3⅜	0	1	2	14⅜	1·87
12 years, 1876-1887	3	7¼	0	4⅞	0	2⅜	3	15¼	3·45
AMMONIUM SALTS = 86 lbs. NITROGEN. (Plot 5.)									
Averages 4 years, 1876-1879	2	7½	0	6⅜	0	4⅜	2	18½	7·45
Averages 4 years, 1880-1883	1	16¼	0	6½	0	0¾	2	3¾	1·76
Averages 4 years, 1884-1887	1	9¾	0	5¼	0	0½	1	15⅛	1·36
12 years, 1876-1887	1	17¼	0	6⅛	0	1⅞	2	5¾	4·06
NITRATE OF SODA = 86 lbs. NITROGEN. (Plot 6.)									
Averages 4 years, 1876-1879	3	2	0	6	0	6¾	3	14¾	9·09
Averages 4 years, 1880-1883	2	0¼	0	6	0	0¾	2	7¼	1·17
Averages 4 years, 1884-1887	1	11	0	3⅞	0	0⅜	1	15¼	1·16
12 years, 1876-1887	2	4⅝	0	5¼	0	2⅜	2	12½	4·93
AMMONIUM SALTS = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 7.)									
Averages 4 years, 1876-1879	5	14	0	8¾	0	15¼	6	18	11·08
Averages 4 years, 1880-1883	7	19⅝	0	6¼	0	8¾	8	14¾	4·95
Averages 4 years, 1884-1887	4	3⅜	0	6¼	0	1⅜	4	10¾	1·49
12 years, 1876-1887	5	18⅛	0	7¼	0	8⅜	6	14½	6·26
NITRATE OF SODA = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 8.)									
Averages 4 years, 1876-1879	5	19	0	8	0	18⅜	7	5⅜	12·82
Averages 4 years, 1880-1883	7	10½	0	6	0	7¾	8	4½	4·70
Averages 4 years, 1884-1887	4	2¾	0	5	0	1½	4	9¼	1·73
12 years, 1876-1887	5	17⅜	0	6⅜	0	9¼	6	13	7·00
SUMMARY. AVERAGE 12 YEARS. 1876-1887.									
Unmanured	1	13½	0	5	0	1¼	1	19¾	3·15
Superphosphate	3	5	0	5⅜	0	2¼	3	13⅜	3·66
Mixed Mineral Manure ..	3	7¼	0	4⅞	0	2⅜	3	15¼	3·45
Ammonium Salts alone ..	1	17¼	0	6⅛	0	1⅞	2	5¾	4·06
Nitrate of Soda alone	2	4⅝	0	5¼	0	2⅜	2	12½	4·93
Ammonium Salts and Mixed Mineral Manure ..	5	18⅛	0	7¼	0	8⅜	6	14½	6·26
Nitrate of Soda and Mixed Mineral Manure ..	5	17⅜	0	6⅜	0	9¼	6	13	7·00

mineral manure alone, with the ammonium salts and mixed mineral manure together, and with the nitrate of soda and the mixed mineral manure together, there was more produce over the second four years than over the first; but there was a marked reduction over the third four years. It is evident, therefore, that the falling off over the second four years in the other cases was not to be accounted for by less favourable seasons only. The conclusion is rather, that by the continuous growth of the crop without manure, or by nitrogenous manures alone, the available supplies of the necessary mineral constituents within the soil, became relatively deficient.

But the great decline over the third four years, under all conditions of manuring, even where there was a full supply of both nitrogen and mineral constituents, shows that the seasons were then less favourable for luxuriant growth. Doubtless, too, with the mineral manures alone, the available supply of nitrogen within the soil, and with the nitrogenous manures alone, the available supply of mineral constituents, had become deficient.

A point of considerable interest brought to view in the last column of the Table is, that there was, under every condition of manuring, a very much larger proportion of diseased tubers over the first four years, when the "Rock" was grown, than afterwards with the "Champion." The very bad result over the first four years was, however, doubtless in great measure due to the character of the seasons also, which included some exceedingly wet and unfavourable ones. With the "Champion," there was, upon the whole, a less proportion of diseased tubers over the third than over the second period of four years. It is true, that the later years were generally drier, and therefore less favourable, both for luxuriance of growth, and for the development of the disease. Nevertheless, it is of interest to observe that the amount of disease was not enhanced by the continuous growth of the crop on the same land, as is frequently assumed to be the case. It is further of interest to note that, with the highest manuring, and the most luxuriant growth, that is where ammonium salts or nitrate of soda, and the mixed mineral manures, were used together, there was, over the second four years, even with the "Champion," a much higher proportion of diseased tubers than with any of the other manures; though, over the third period, of drier seasons, the proportion was about as low as under the other conditions of manuring.

In the summary at the bottom of the Table is given the average produce over the total period of twelve years, under each of the different conditions as to manuring. It will suffice to call special attention to the column showing the total produce of tubers—good, small, and diseased—and to the last column, showing the average percentage of diseased tubers, under each condition of manuring.

In the first place, the average produce over twelve years without any manure, is not quite 2 tons per acre; and it will be remembered that there was a considerable decline from period to period under this exhausting treatment. Nevertheless, as will be seen further on, this

low yield without manure, for twelve years in succession on the same land, is about as much as the average produce under ordinary cultivation in the United States, and nearly two-thirds as much as in some important European countries.

By superphosphate of lime alone the produce is raised from an average of scarcely 2, to nearly 3¾ tons; and by a mixed mineral manure, containing, besides superphosphate of lime, salts of potash, soda, and magnesia, to just over 3¾ tons, that is to very little more than by the superphosphate alone. It is evident, therefore, that up to this amount of production, the character of the exhaustion induced by the growth of the crop on this land, which was, agriculturally speaking, in a somewhat exhausted condition, was much more that of available phosphoric acid than of potash, or the other bases.

In reference to this increase of produce of Potatoes by mineral manures alone, it may be observed that the result is quite consistent with that obtained with root-crops having comparatively shallow root-development; and in such cases the source of the nitrogen is chiefly the store of it in the surface soil. The beneficial effects of mineral manures, and especially of phosphates, are indeed observed generally with ripened as well as with succulent crops which are spring sown, and which have, with a short period of growth, comparatively superficial rooting, and which rely therefore much on the stores of the surface soil.

It is remarkable that there is much less increase of produce of Potatoes by nitrogenous manures alone than by mineral manures alone.

Thus, by ammonium salts alone there is an average produce of scarcely 2 tons 6 cwts., or only about 6 cwts. more than without manure; and with nitrate of soda alone there is an average of only 2 tons 12½ cwts. per acre. The better result by nitrate of soda than by ammonium salts is doubtless due to the nitrogenous supply being more immediately available, and more rapidly distributed within the soil, and so inducing a more extended development of feeding root.

These negative results by the nitrogenous manures alone, confirm the conclusion that by the continuous growth of the crop on this land, it was the available supply of mineral constituents within the root-range of the plant, more than that of nitrogen, that became deficient.

The last two lines of the Table show, that with the mixed mineral manure and ammonium salts together, there was an average of about 6 tons 14½ cwts., and with the mixed mineral manure and the same amount of nitrogen as nitrate of soda, an average of 6 tons 13 cwts.; that is, nearly twice as much as with the mineral manure alone, and much more than twice as much as with the nitrogenous manure alone. These amounts, it may be observed, are higher than the estimated average produce of either Division of the United Kingdom; indeed, more than one and a half time as high as in Ireland in recent years. At any rate the amounts of produce obtained by the mixture of both mineral and nitrogenous manures are sufficient to show that, although the land is by no means specially adapted for Potatoes, the results may

be taken as normal and trustworthy; and as fairly indicating the characteristic manurial requirements of the crop; and the conclusion is that, in an agriculturally exhausted soil, both mineral and nitrogenous manures are required to give full crops.

Finally, in reference to this summary of the results, the last column shows the average percentage of diseased tubers under each of the several conditions as to manuring. It is seen that, without manure, and with purely mineral manures, the proportion of diseased tubers is much less than where nitrogenous manures were applied; and again, that it was less where the nitrogenous manures were applied alone, than when in conjunction with mineral manures; and where, consequently, the luxuriance of growth, and the amounts of produce, were the greatest. To this result I shall have to refer again further on.

PRODUCE WITHOUT MANURE, AND WITH FARM-YARD MANURE.

Table II. (p. 7), gives the results obtained by farm-yard manure, alone, or with other manures, compared with those without manure. It will be seen that the average produce per acre, per annum, is not, as in the case of the artificial mauure series, given for the first, second, and third periods of four years each, and for the twelve years, but for six, six, and twelve years; there having been, as the Table shows, a change in the manuring, in two cases after six years, and in the third after seven years; and, for comparison with the manured plots, the produce without manure is now also given for six, six, and twelve years. It is to be understood, however, that, as in the other experiments, so in these, the "Rock" was grown in the first four years, and the "Champion" afterwards.

As before, we may confine detailed attention to the column of average total produce of tubers—good, small, and diseased, together—and to the last column, showing the average percentage of diseased Potatoes in the total produce.

As already shown, the average produce without manure declined considerably over the later years.

The second division of the Table shows that, with an annual application of 14 tons farm-yard manure per acre, supplying perhaps about 200 lbs. of nitrogen per acre per annum, there was an average produce over six years of only about $5\frac{1}{4}$ tons; and, as shown in the third division, the addition of superphosphate of lime raised the produce to scarcely 5 tons 12 cwts., or by only about 7 cwts. The fourth division shows, however, that by the further addition of nitrate of soda, supplying 86 lbs. of nitrogen per acre per annum, in a much more readily available condition than most of that in the farm-yard manure, the average annual produce of tubers was raised to 7 tons 2 cwts., or by $1\frac{1}{8}$ ton more.

Comparing these results with those obtained by artificial manures alone, we find that farm-yard manure, which, besides an abundance of mineral matters, and a large amount of organic substance rich in carbon,

supplied annually about 200 lbs. of nitrogen, gave considerably less produce than an artificial mixture of mineral manures and ammonium salts or nitrate of soda, supplying only 86 lbs. of nitrogen per acre per annum. The fact is, that it is only the comparatively small proportion of the nitrogen of farm-yard manure which is due to the liquid dejections of the animals, that is in a readily and rapidly available condition; whilst that due to more or less digested matter passing in the fœces, is more slowly available, and that in the litter remains a very long time inactive. Hence, the addition of nitrogen as nitrate of soda to the farm-yard manure had a very marked effect.

TABLE II.

POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Manures and Produce per acre per annum; 12 years, 1876-1887.

	Good.	Small.	Diseased.	Total.	Per cent. Diseased in Total.
UNMANURED, 12 years. (Plot 1.)					
	Tons. cwts.	Tons. cwts	Tons. cwts.	Tons. cwts.	Per cent.
Averages: 6 years, 1876-1881	1 17⅛	0 5⅜	0 2	2 5½	4·27
Averages: 6 years, 1882-1887	1 9	0 4¼	0 0½	1 13¾	1·63
12 years, 1876-1887	1 13½	0 5	0 1¼	1 19¾	3·15
FARM-YARD MANURE, 6 YEARS; UNMANURED, 6 YEARS. (Plot 2.)					
Averages: 6 years, 1876-1881	4 11⅞	0 7	0 5¾	5 4⅝	5·54
Averages: 6 years, 1882-1887	2 13⅛	0 6⅛	0 1¾	3 1	2·88
12 years, 1876-1887	3 12½	0 6½	0 3¾	4 2¾	4·56
FARM-YARD MANURE AND SUPERPHOSPHATE, 7 YEARS; FARM-YARD MANURE ALONE, 5 YEARS. (Plot 3.)					
Averages: 6 years, 1876-1881	4 16⅞	0 7½	0 7½	5 11⅝	6·73
Averages: 6 years, 1882-1887	3 17½	0 5⅜	0 2¼	4 5⅛	2·58
12 years, 1876-1887	4 7⅛	0 6⅜	0 4⅞	4 18⅜	4·93
FARM-YARD MANURE, SUPERPHOSPHATE, AND NITRATE OF SODA, 6 YEARS; FARM-YARD MANURE ALONE, 6 YEARS. (Plot 4.) (*)					
Averages: 6 years, 1876-1881	5 17¾	0 6⅜	0 17⅛	7 2½	12·56
Averages: 6 years, 1882-1887	3 13	0 5½	0 1¾	4 0¼	2·21
12 years, 1876-1887	4 15⅜	0 6⅛	0 9¾	5 11¼	8·82
SUMMARY. AVERAGE 12 YEARS, 1876-1887.					
Unmanured	1 13½	0 5	0 1¼	1 19¾	3·15
Farm-yard Manure, 6 years; Unmanured, 6 years	3 12½	0 6½	0 3¾	4 2¾	4·56
Farm-yard Manure and Superphosphate, 7 years; Farm-yard Manure alone, 5 years	4 7⅛	0 6⅜	0 4⅞	4 18⅜	4·93
Farm-yard Manure, Superphosphate, and Nitrate Soda, 6 years; Farm-yard Manure alone, 6 years (*)	4 15⅜	0 6⅛	0 9¾	5 11¼	8·82

(*) The Superphosphate, but not the Nitrate, was applied in the seventh year, 1882.

The next point to consider is the effects of the residue of the previously applied manures, as shown in the second line of each division of the Table.

The second division shows that, after the application of farm-yard manure, containing about 200 lbs. of nitrogen per acre, for six years in succession, there was, over the next six years without manure, a falling off in the annual average produce of tubers from nearly 5¼ to little over 3 tons;—that is, to less than the average produce obtained by artificial mineral manures without any nitrogen. There is here striking evidence of the very slow action of the large residue, mineral as well as nitrogenous, of the farm-yard manure.

The third division shows that with the cessation of the addition of superphosphate to the farm-yard manure, the crop was reduced from 5 tons 12 cwts. to 4 tons 5 cwts. It is true that the later seasons were less favourable for luxuriance. Still, the evidence points to the conclusion that the residue of the superphosphate had comparatively little effect; and that, in fact, it remained within the soil in a condition only slowly available.

Lastly, the fourth division shows that with the cessation of the application of the nitrate of soda, the average produce was reduced from 7 tons 2 cwts. to only 4 tons, or by more than 3 tons per acre per annum. Allowing for the difference in the character of the seasons, there would still appear to have been practically no immediately available residue of the nitrogen of the nitrate left within the root-range of the crop.

The fact that, over the last six years, farm-yard manure, together with the residue of previously applied farm-yard manure, superphosphate, and nitrate of soda, only yielded an average of about 4 tons of tubers; and that farm-yard manure and the residue of farm-yard manure and superphosphate, only gave about 4¼ tons, whilst farm-yard manure alone gave over the first six years 5¼ tons, is clear indication that the later seasons were somewhat less favourable for luxuriance with such manures.

As in the case of the artificial manures, so now with the farm-yard manure series, the last column of the Table shows a very much larger proportion of diseased tubers over the earlier than over the later years; and, consistently with the results with the artificial manures, there is the largest proportion where there was the largest supply of nitrogen; that is where nitrate of soda was added to the farm-yard manure. In comparing period with period, however, it must not be forgotten that the "Rock" was grown in the first four years, and the "Champion" afterwards.

The summary given at the foot of the Table shows the average results for each of the farm-yard manure plots, over the whole period of twelve years. The results have, of course, to be read with due reference to the changes in the manuring over the later years, and hence are not very direct in their indications.

It is somewhat remarkable that on neither plot with farm-yard

manure, not even where it was applied each year of the twelve, was there so much produce as on the artificially manured plots receiving both mineral and nitrogenous manures. Indeed, not even where nitrate of soda was applied in addition to the farm-yard manure during the first six years, did the average produce of the twelve years amount to six tons of tubers.

The last column of the summary shows, as before, that the proportion of diseased tubers was the greater, the greater the amount of nitrogen supplied, and the greater the luxuriance.

Upon the whole it is obvious that, in the case of this somewhat agriculturally exhausted arable land, mineral manures alone had more effect than nitrogenous manures alone; but that, mineral constituents being adequately supplied, the further addition of nitrogenous manures was essential to obtain anything like full crops.

CONSTITUENTS IN THE CROPS PER ACRE PER ANNUM.

1.—*Artificial Manure Series.*

It will be of interest next to consider, what is the increased amount of some of the more important constituents of the tubers stored up in the crop, under the influence of the different manures; and especially what is the increased amount of them stored up, for a given quantity of nitrogen supplied in manure. Results of the analyses of the various crops, to which I shall call special attention when considering the percentage composition of the tubers, supply the data for estimates on these points.

Table III. (p. 10), gives the results for the artificially manured series.

The upper division of the Table shows the amounts, in lbs., of total dry or solid matter, of nitrogen, of total mineral matter (or ash), of potash, of phosphoric acid, of sulphuric acid, and of chlorine, in the average produce, per acre, per annum, over the twelve years, without manure, and with each of the six different artificial manures. These are the total quantities in the crops per acre; but the amount of seed Potatoes planted would, on the average, supply to the soil perhaps as much as one-third or more of the various constituents as were removed in the unmanured produce; and, of course, the same actual amounts, but a much less proportion of the whole in the produce, would be supplied in the case of the manured crops. It seems desirable, however, that the Table should give the actual amounts in the crops, rather than any mere estimates founded on uncertain data; especially as the figures in the remaining divisions of the Table, which relate to the increase of constituents in the crops under the influence of the different manures, would not be affected by any correction for the amounts supplied in the seed.

In the second division are given the increased amounts of each of the same constituents per acre in the average produce of each of the manured plots, over the amount in the unmanured produce.

The third division shows the amounts of the several constituents in

the increase of produce over that without manure, for 100 of nitrogen supplied in manure.

In the fourth division are shown the actual amounts of increase of the constituents per acre by the nitrogenous and mineral manure together, over those by the mineral manure alone; and the fifth and last division shows these increased amounts over those by the mineral manure alone, calculated for 100 of nitrogen supplied in manure.

TABLE III.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Constituents per acre per annum in Total Tubers. Average of 12 years, 1876-1887.

	Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Potash.	Phosphoric Acid.	Sulphuric Acid.	Chlorine.
Constituents per Acre per Annum.							
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Unmanured	1250	14·9	37·4	20·8	5·51	3·25	1·99
Superphosphate.. ..	2203	20·5	87·9	50·8	11·28	4·97	4·13
Mixed Mineral Manure	2235	19·9	93·6	53·9	11·91	5·75	4·44
Ammonium Salts ..	1343	19·7	39·5	21·6	4·74	3·23	3·70
Nitrate of Soda.. ..	1558	23·0	44·1	23·1	5·59	3·15	1·83
Ammonium Salts and Mixed Mineral Manure	3857	48·1	153·7	88·3	16·80	8·30	11·02
Nitrate of Soda and Mixed Mineral Manure	3844	50·8	149·0	85·2	17·51	8·61	4·16
Increase of Constituents per Acre per Annum over Unmanured.							
Superphosphate.. ..	953	5·6	50·5	30·0	5·77	1·72	2·14
Mixed Mineral Manure	985	5·0	56·2	33·1	6·40	2·50	2·45
Ammonium Salts ..	93	4·8	2·1	0·8	−0·77	−0·02	1·71
Nitrate of Soda.. ..	308	8·1	6·7	2·3	0·08	−0·10	−0·16
Ammonium Salts and Mixed Mineral Manure	2607	33·2	116·3	67·5	11·29	5·05	9·03
Nitrate of Soda and Mixed Mineral Manure	2594	35·9	111·6	64·4	12·00	5·36	2·17
Increase of Constituents for 100 Nitrogen in Manure over Unmanured.							
Ammonium Salts ..	108	5·6	2·4	0·9	−0·90	−0·02	1·99
Nitrate of Soda.. ..	358	9·4	7·8	2·7	0·09	−0·12	−0·19
Ammonium Salts and Mixed Mineral Manure	3031	38·6	135·2	78·5	13·13	5·87	10·50
Nitrate of Soda and Mixed Mineral Manure	3016	41·7	129·8	74·9	13·95	6·23	2·52
Increase of Constituents per Acre per Annum over Mixed Mineral Manure.							
Ammonium Salts and Mixed Mineral Manure	1622	28·2	60·1	34·4	4·89	2·55	6·58
Nitrate of Soda and Mixed Mineral Manure	1609	30·9	55·4	31·3	5·60	2·86	−0·28
Increase of Constituents for 100 Nitrogen in Manure over Mixed Mineral Manure.							
Ammonium Salts and Mixed Mineral Manure	1886	32·8	69·9	40·0	5·69	2·97	7·65
Nitrate of Soda and Mixed Mineral Manure	1871	35·9	64·4	36·4	6·51	3·33	−0·33

Referring to the first division, it is seen that whilst without manure there is an average of only 1250 lbs., or little more than 11 cwts. of total dry or solid matter, produced per acre, there is not much more (1343 lbs.) with purely nitrogenous manure as ammonium salts, and scarcely one-fourth more (1558 lbs.) with the same amount of nitrogen as nitrate of soda. There is, on the other hand, with the purely mineral manures, nearly 20 cwts. (2203 and 2235 lbs.), and with the nitrogenous and mineral manures together an average of about 34½ cwts. (3857 and 3844 lbs.) of solid matter produced per acre per annum.

The average amount of nitrogen annually stored up in the tubers grown without manure was, notwithstanding the amount supplied in the seed, only 14·9 lbs.; or less than would be yielded in wheat or barley under similar circumstances. By mineral manures alone the amount was raised to about 20 lbs., or to nearly as much as in wheat or barley under the same conditions. On the other hand, the direct application of 86 lbs. of nitrogen, per acre per annum, when as ammonium salts alone, only raised the amount taken up to 19·7 lbs., and when as nitrate of soda alone, to only 23·0 lbs. The incapacity of the plant to avail itself of the supplied nitrogen in the absence of a sufficient available supply of mineral constituents, is here very strikingly illustrated. With the same applications of nitrogen, but in conjunction with the mixed mineral manure, the amount of nitrogen stored up in the tubers is raised from about 20 to about 50 lbs.;—48·1 lbs. with the ammonium salts, and 50·8 lbs. with the nitrate of soda.

The remaining columns of the upper division of the Table show that very little more of either the total, or the individual, mineral constituents, was taken up under the influence of the purely nitrogenous manures, than without manure. With the mineral manures alone, however, there was more than twice as much, both of total mineral constituents, and of the more important individual ones, taken up; and there was three or four times as much taken up when the nitrogenous and the mineral manures were used together. The figures relating to potash and phosphoric acid afford striking illustrations on these points.

The influence of the manures on the amounts of constituents taken up by the crop is, however, brought out more clearly still in the second division of the Table, which shows the amounts of each constituent stored up more than without manure.

It is seen that, whilst the purely nitrogenous manures have but little increased the production of solid matter, the mineral manures alone have increased it by nearly 1000 lbs. (953 and 985 lbs.) per acre, and the nitrogenous and mineral manures together have increased it by about 2600 lbs. (2607 and 2594 lbs.), or by more than 23 cwts. per acre.

It is remarkable that the purely nitrogenous manures, supplying 86 lbs. of nitrogen, have scarcely increased the assimilation of nitrogen more than the purely mineral manures; whilst the application of the two together has increased it very much—by 33·2 and 35·9 lbs. These latter amounts, when calculated for 100 nitrogen supplied in manure, as

shown in the third division of the Table, represent a recovery in the increase of the crop of 38·6 and 41·7 per cent. of the nitrogen supplied in the manure. But when the increased assimilation of nitrogen is calculated, not over the amount in the unmanured produce, but over that in the produce by the mixed mineral manure alone, it represents, as shown in the bottom division, only 32·8 and 35·9 per cent. recovered.

These amounts of nitrogen recovered in the increased produce of Potatoes, for 100 supplied in manure, are less than were so recovered in Mangel Wurzel receiving similar manures. Thus the amount of nitrogen recovered for 100 supplied (with mineral manures) when as ammonium salts, was with Mangel Wurzel 42·3, against only 32·8 with Potatoes; and when the supply was as nitrate of soda, 59·9 per cent. of the nitrogen was recovered as increase in the Mangel Wurzel, against only 35·9 per cent. with the Potatoes. The proportion recovered in Potatoes is, however, approximately the same as in the case of Wheat, but less than that in the case of the spring sown Barley.

Referring in less detail to the amounts of other constituents taken up under the influence of the different manures, it is seen that by far the most prominent increase is in the potash, and second in order comes phosphoric acid. It is remarkable that, by the use of superphosphate of lime alone, 30 lbs. more potash are taken up per acre than without manure, and that only 3 lbs. more are taken up under the influence of the mixed mineral manure alone, which, besides superphosphate, supplied annually nearly 150 lbs. of potash. It is well known that one special effect of superphosphate of lime applied to spring sown crops, is greatly to increase the development of feeding-root within the surface soil; and here it would seem that under its influence, probably on both soil and plant, the Potato has been enabled to obtain a large amount of potash from the stores of the surface soil.

The purely nitrogenous manures, on the other hand, have not enabled the plant to take up an appreciably increased amount of potash.

It is, however, where the mineral and nitrogenous manures were applied together, that the greatest amount of potash is taken up. Indeed, under the influence of this combination, nearly one-half of the 150 lbs. of potash annually supplied is recovered in the increased produce, 67·5 lbs. in one case, and 64·4 lbs. in the other.

But little is definitely known of the special function of individual mineral constituents in vegetation. It is, however, pretty clearly established that the presence of potash is essential for the formation of the chief non-nitrogenous matters—starch and sugar. The published results of experiments at Rothamsted have shown that the proportion of potash in the ash of wheat was the greater, the better matured the grain—that is the larger the proportion of starch it contained; and here in the potato we find a greatly increased amount of potash in the heaviest crops, that is to say in those in which the largest amounts of starch have been formed.

The accumulation of phosphoric acid, on the other hand, is more directly connected with the assimilation of nitrogen, and the formation

of the nitrogenous compounds. The amounts of phosphoric acid are seen to be much less than those of potash; but the differences in the amounts bear an obvious, though not a numerically direct, relation, to the differences in the amounts of nitrogen in the crops.

Sulphuric acid is also essential, as a supply of sulphur, to the formation of certain nitrogenous constituents of the plant. It is seen that the quantities are considerably less than those of phosphoric acid, and that the variations have some, but not a numerically direct connection with the amounts of nitrogen in the crops. It is to be borne in mind, however, that the methods of preparing ashes for analysis, do not in all cases secure the retention in them, as sulphuric acid, of the whole of the sulphur in the substance incinerated. On the other hand, the ashes, especially of other than such fixed products as ripened seeds, generally contain sulphuric acid existing as such in the crude product.

The amounts of the chlorine taken up by the plant are very variable, and have relation chiefly to the supplies by manure, and probably none to the formation of any organic compounds.

2.—*Farm-yard Manure Series.*

Let us now turn to the consideration of similar particulars relating to the farm-yard manure series of plots—that is to what may be called the chemical statistics of the crops.

Table IV. (p. 14) gives the results for the first and second periods of six years each, separately; also the difference between the two, or the results for the twelve years, as the case may be.

It is seen that, without manure, there is less of every constituent stored up in the crop over the second than over the first period of six years. This reduction of course represents exhaustion, as well as any influence of the seasons. In the case of each of the manured plots, the whole, or some item, of the manure, was omitted over the second period, so that some reduction in the yield would be anticipated; and it is seen that there was, under each condition of manuring, a reduction, and generally a very great reduction, in the amount stored up of every constituent, with the exception of the nitrogen in one case, as indicated by the + sign.

The upper division of the Table shows the actual quantities of the several constituents stored up per acre; but the significance of the facts will be better appreciated by an examination of the increased amounts over those without manure, as given in the second division of the Table.

It will be remembered that the quantity of farm-yard manure annually applied per acre was estimated to contain about 200 lbs. of nitrogen, besides a very large amount of mineral constituents. Yet, in no case was the increased yield of solid substance in the crop so great as was obtained by an artificial mixture of mineral and nitrogenous manure, supplying only 86 lbs. of nitrogen, but in a more readily available condition. Nor was the increased assimilation of any one of

TABLE IV.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Constituents per acre per annum in Total Tubers. 12 years, 1876-1887.

		Dry Matter.	Nitrogen.	Mineral Matter (Ash).	Potash.	Phosphoric Acid.	Sulphuric Acid.	Chlorine.
Constituents per Acre per Annum.								
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Unmanured	6 yrs., 1876-81	1413	15·4	45·4	25·2	6·66	3·95	2·42
	6 yrs., 1882-87	1079	13·9	30·4	16·8	4·47	2·64	1·62
	Difference...	334	1·5	15·0	8·4	2·21	1·31	0·80
Farmyard Manure ...	6 yrs., 1876-81	3022	28·2	117·1	67·2	14·82	6·77	8·36
Unmanured	6 yrs., 1882-87	1944	24·3	58·8	33·8	7·45	3·40	4·21
	Difference...	1078	3·9	58·3	33·4	7·37	3·37	4·17
Farmyard Manure and Superphosphate	6 yrs., 1876-81	3188	29·0	130·0	74·7	15·51	7·61	10·27
Farmyard Manure alone	6 yrs., 1882-87	2512	33·6	91·6	52·6	10·92	5·36	7·23
	Difference...	676	+4·6	38·4	22·1	4·59	2·25	3·04
Farmyard Manure, Superphosphate, and Nitrate	6 yrs., 1876-81	3886	48·7	148·1	83·7	17·95	9·00	6·92
Farmyard Manure alone	6 yrs., 1882-87	2327	33·4	84·5	47·7	10·24	5·14	3·95
	Difference...	1559	15·3	63·6	36·0	7·71	3·86	2·97
Increase of Constituents per Acre per Annum over Unmanured.								
Farmyard Manure ...	6 yrs., 1876-81	1609	12·8	71·7	42·0	8·14	2·82	5·96
Farmyard Manure—Residue	6 yrs., 1882-87	865	10·4	28·4	17·0	2·98	0·76	2·59
	Difference...	744	2·4	43·3	25·0	5·16	2·06	3·37
Farmyard Manure and Superphosphate	6 yrs., 1876-81	1775	13·6	84·6	49·5	8·83	3·66	7·35
Farmyard Manure and Residue.. ...	6 yrs., 1882-87	1433	19·7	61·2	35·8	6·45	2·72	5·61
	Difference...	342	+ 6·1	23·4	13·7	2·38	0·94	2·24
Farmyard Manure, Superphosphate, and Nitrate	6 yrs., 1876-81	2473	33·3	102·7	58·5	11·27	5·05	4·50
Farmyard Manure and Residue.. ...	6 yrs., 1882-87	1248	19·5	54·1	30·9	5·77	2·50	2·33
	Difference...	1225	13·8	48·6	27·6	5·50	2·55	2·17
Increase of Constituents for 100 Nitrogen in Manure over Unmanured.								
Farmyard Manure ...	6 yrs., 1876-81	805	6·4	35·9	21·0	4·07	1·41	2·98
Farmyard Manure—Residue	6 yrs., 1882-87	432	5·2	14·2	8·5	1·49	0·38	1·30
	12 years...	1237	11·6	50·1	29·5	5·56	1·79	4·28
Farmyard Manure and Superphosphate	6 yrs., 1876-81	888	6·8	42·3	24·8	4·42	1·83	3·92
Farmyard Manure, and Residue... ...	6 yrs., 1882-87	717	9·9	30·6	17·9	3·23	1·36	2·81
	12 years...	802	8·3	36·5	21·3	3·82	1·60	3·37
Increase of Constituents for 100 Nitrogen as Nitrate, over Farmyard Manure and Superphosphate.								
Farmyard Manure, Superphosphate, and Nitrate	6 yrs., 1876-81	812	22·9	21·0	10·5	2·84	1·62	−3·90

the individual constituents, so great under the influence of the farm-yard manure, as when these were applied in the rapidly available condition as in the artificial mixtures.

It has been seen that, with the artificial manures, there was, of the nitrogen supplied, about 40 per cent. recovered in the increased crop (38·6 and 41·7) reckoned over the produce without manure, and about 34·5 per cent. (32·8 and 35·9) reckoned over the produce by purely mineral manures. But here, when the supply was in farm-yard manure, there was, as the third division of the Table shows, in one case only 6·4, and in another only 6·8 per cent. of the nitrogen so supplied, recovered in the immediate increase over the six years of the application; and, notwithstanding the great accumulation that would take place, there was only 8·3 per cent. recovered in the increase when the application was continued for 12 consecutive years.

It is further seen that after farm-yard manure had been applied for six years in succession, and it had yielded up to the crop only 6·4 per cent. of its nitrogen, over the next six years without manure, the large unrecovered residue only yielded 5·2 per cent. more; that is, only 11·6 per cent. in all, over the twelve years.

In the case of other crops it has been found that only a small proportion of the nitrogen of farm-yard manure was taken up in the year of the application. But these results seem to indicate that the Potato is able to avail itself of a less proportion of the nitrogen of the manure than any other farm crop. Yet, in ordinary practice, farm-yard manure is not only largely relied upon for Potatoes, but is often applied in larger quantity for them than for any other crop. It is probable that, independently of its liberal supply of all necessary constituents, its beneficial effects are in a considerable degree due to its influence on the mechanical condition of the soil, rendering it more porous and easily permeable to the surface roots, upon the development of which the success of the crop so much depends. Then, again, something may be due to an increased temperature of the surface soil engendered by the decomposition of so large an amount of organic matter within it; whilst the carbonic acid evolved in the decomposition will, with the aid of moisture, serve to render the mineral resources of the soil more soluble.

The Potato is, indeed, largely a kitchen and market garden crop, as well as a farm crop; and for the production of garden vegetables generally very large quantities of farm or stable manure are applied, beyond what is required as a mere supply of constituents to the crops—the process being to a great extent one of forcing, as above referred to; and a necessary result is a great accumulation of unexhausted residue within the soil.

It will be of interest to give here a few illustrations of the manuring and produce of potatoes, in some localities where they constitute an important item of production.

I will first refer to the evidence given before *The Select Committee on the Potato Crop*. The practice of several growers in Forfarshire is

given. According to the various statements, the crop is generally grown in six, seven, or eight year rotation ; and farm-yard, or stable manure, is largely relied upon ; but it is frequently supplemented by liberal dressings of artificial manures, both mineral and nitrogenous. The quantity of dung used ranges from 12 to 14, and even to more than 20 tons per acre ; and sometimes as much as 10 cwts. of artificial manure is also used, consisting chiefly of superphosphate or dissolved bones, and potash salts, or kainit ; and six tons is reckoned a fair crop. In East Lothian the crop is also grown in six, seven, or eight year rotation ; as much as 30 tons of dung is used for the late crop, with 5 to 10 cwts. of artificials, consisting of guano or dissolved bones, and sometimes potash salts ; and the crop is estimated at 6 to 8 tons per acre. For an early crop as much as 40 tons of dung, and 10 cwts. of a mixture of superphosphate, guano, and dissolved bones, are used, and only about 4 or 5 tons of produce is obtained. It was stated that, in Dublin County, potatoes are grown in four or five years course, with dung and artificials ; the latter consisting of superphosphate, potash salts, and salts of ammonia or nitrate of soda ; and 8 tons is considered a good crop. In Kent, one witness reports the growth of the crop once in five years, using 12 to 20 loads of farm-yard manure, with superphosphate, kainit, and sulphate of ammonia ; and getting 10 to 11 tons of marketable tubers, and 2 tons of small. In another case in Kent 30 to 35 tons of dung are used.

Mr. T. H. Middleton, of Invergordon, Ross-shire, has kindly furnished me with further particulars as to the manuring and produce of potatoes in Scotland. He states that it is common to use 15 to 20 tons of farm-yard manure, with bone meal and superphosphate in addition. Or, sometimes, Potatoes are grown with artificial manure only ; about 10 cwts., consisting of 3 cwts. superphosphate, 2 cwts. bone meal, 3 cwts. of kainit, and 2 cwts. sulphate of ammonia ; and an average crop is about 6½ tons of Regents, or 7½ tons of Magnum Bonums. At a farm in Ayrshire, the practice for the growth of an early crop is to use 20 to 30 tons of dung, with 5 cwts. of kainit, and 8 or 10 cwts. of other artificial manures ; consisting of good guano, or phosphatic guano with sulphate of ammonia, or any mixture containing 8 to 10 per cent. of ammonia, 20 to 30 per cent. of phosphate, and 3 to 5 per cent. of potash. In Forfarshire the crop is usually grown in an eight year course ; 15 to 20 tons of farm-yard manure are used, with artificial manures in addition ; 6 or 7 tons is reckoned an average crop, 10 tons a very good one, and 4 to 5 tons a bad crop. Sometimes, however, Potatoes are grown after three years grass, with artificial manures alone. In East and Mid Lothian, Potatoes are generally grown in a six year course ; with about 20 tons of farm-yard manure, and artificial manures in addition. The description of the latter varies considerably ; but the following is sometimes used :—2 cwts. ground bones, 1 cwt. vitriolized bones, 1½ cwt. mineral superphosphate, 1 cwt. sulphate of potash, and ½ cwt. sulphate of ammonia—in all 6 cwts. An average crop is 6 or 7 tons, and in very favourable seasons 10 or even 12 tons

are obtained. Sometimes, however, in the Lothians, Potatoes are grown in six year course, after two years grass, and with artificial manure only, the farm-yard manure being reserved for the Turnips.

Such are typical cases of the manuring and produce of Potatoes when grown as a farm rotation crop. But it will be well to consider the conditions under which the crop is grown in a specially suitable climate for the early market. On this point I have been favoured with a very interesting account of Potato growing in Jersey, by Mr. F. Woodland Toms, the Official Analyst, of St. Heliers. The rents for suitable land are very high. No special rotation is followed. Potatoes are grown two or three years, then corn, then grass for a few years, and then Potatoes again. From 25 to 30 tons of farm-yard manure, or sea-weed, are applied per acre, with 8 to 12 cwts. of artificial manure, containing about 8 per cent. of ammonia, and 20 per cent. of soluble phosphate. Including rent, the total expenditure for the crop is often as much as £45 per acre, and sometimes even more; but almost always a second crop of some kind is taken the same year, after the removal of the Potatoes. The earliest crops, which command very high prices, average about 6 tons. But the average crop of the year ranges from 8 to 10 tons, according to season, with an average price of about £6 per ton. The price fluctuates, however, considerably, from season to season, and very much more throughout the season. Thus, it ranged, in 1886, from £10 per ton about the middle of June, to £3 11s. 6d. in the middle of August; in 1887, from £22 10s. at the end of May, to £6 11s. at the end of August; and in 1888, from £20 12s. 6d. at the beginning of June, to about £2 6s. in September and October.(*)

Lastly, Mr. C. B. Edwardes, of Peterborough, informs me that the market gardeners in the neighbourhood of Sandy, St. Neots, and Biggleswade, frequently apply from 30 to 60 tons of London stable manure per acre, for Potatoes, and even as much as 100 tons have, in some cases, been used. Frequently, too, besides the dung, ½ to 1 ton of artificial manure, or from 100 to 200 bushels of soot, are also used.

It will be seen that the foregoing statements of the actual practice in the growth of Potatoes, in different localities, are quite consistent with the experimental results that have been adduced, in showing how large is the amount of manure required in proportion to the amount of produce obtained.

INFLUENCE OF SEASON AND MANURING ON THE PERCENTAGE COMPOSITION OF THE TUBERS.

The next point to consider is the percentage composition of the Potato, and the direction, and the degree, in which this is influenced

(*) Since the above was in type, my attention has been called to Mr. W. E. Bear's article, entitled, *Glimpses of Farming in the Channel Islands*, in the last number of the Journal of the Royal Agricultural Society. He there gives a very interesting account of the farming in Jersey, and especially of the treatment and produce of the potato crop, and to this I would refer for further details on the subject.

TABLE V.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Mean percentage composition of the *Good* Tubers; 12 years, 1876-1887.

	Specific gravity of the Tubers.	Per cent. in Fresh Tubers.			Per cent. in Dry Matter.	
		Dry Matter.	Mineral Matter (Ash).	Nitrogen.	Mineral Matter (Ash).	Nitrogen.
UNMANURED. (Plot 1.)						
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Averages 4 years, 1876-1879	1·107	26·8	0·92	0·260	3·48	0·979
Averages 4 years, 1880-1883	1·125	29·3	0·81	0·345	2·77	1·176
Averages 4 years, 1884-1887	1·122	28·2	0·79	0·397	2·82	1·409
Averages 12 years, 1876-1887	1·118	28·1	0·84	0·334	3·02	1·188
SUPERPHOSPHATE OF LIME. (Plot 9.)						
Averages 4 years, 1876-1879	1·102	24·4	1·13	0·197	4·64	0·805
Averages 4 years, 1880-1883	1·122	28·2	1·06	0·226	3·76	0·806
Averages 4 years, 1884-1887	1·121	27·8	1·02	0·325	3·67	1·165
Averages 12 years, 1876-1887	1·115	26·8	1·07	0·249	4·02	0·925
MIXED MINERAL MANURE. (Plot 10.)						
Averages 4 years, 1876-1879	1·102	24·2	1·15	0·189	4·74	0·782
Averages 4 years, 1880-1883	1·121	28·0	1·09	0·222	3·89	0·794
Averages 4 years, 1884-1887	1·118	27·3	1·09	0·297	4·00	1·090
Averages 12 years, 1876-1887	1·114	26·5	1·11	0·236	4·21	0·888
AMMONIUM SALTS = 86 lbs. NITROGEN. (Plot 5.)						
Averages 4 years, 1876-1879	1·099	23·4	0·75	0·298	3·23	1·280
Averages 4 years, 1880-1883	1·116	27·8	0·80	0·386	2·89	1·390
Averages 4 years, 1884-1887	1·114	27·3	0·76	0·468	2·77	1·717
Averages 12 years, 1876-1887	1·110	26·2	0·77	0·384	2·96	1·462
NITRATE OF SODA = 86 lbs. NITROGEN. (Plot 6.)						
Averages 4 years, 1876-1879	1·104	24·6	0·74	0·314	3·03	1·282
Averages 4 years, 1880-1883	1·117	27·9	0·78	0·399	2·81	1·431
Averages 4 years, 1884-1887	1·115	27·2	0·73	0·463	2·70	1·707
Averages 12 years, 1876-1887	1·112	26·5	0·75	0·392	2·84	1·473
AMMONIUM SALTS = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 7.)						
Averages 4 years, 1876-1879	1·096	24·0	1·06	0·250	4·44	1·054
Averages 4 years, 1880-1883	1·110	26·6	0·99	0·305	3·72	1·149
Averages 4 years, 1884-1887	1·107	26·2	1·01	0·401	3·85	1·535
Averages 12 years, 1876-1887	1·104	25·6	1·02	0·319	4·00	1·246
NITRATE OF SODA = 86 lbs. NITROGEN, AND MIXED MINERAL MANURE. (Plot 8.)						
Averages 4 years, 1876-1879	1·100	24·4	1·06	0·265	4·37	1·096
Averages 4 years, 1880-1883	1·115	26·6	0·97	0·339	3·70	1·273
Averages 4 years, 1884-1887	1·110	26·3	0·95	0·419	3·62	1·602
Averages 12 years, 1876-1887	1·108	25·8	1·00	0·341	3·90	1·324
SUMMARY. AVERAGE 12 YEARS, 1876-1887.						
Unmanured	1·118	28·1	0·84	0·334	3·02	1·188
Superphosphate	1·115	26·8	1·07	0·249	4·02	0·925
Mixed Mineral Manure	1·114	26·5	1·11	0·236	4·21	0·888
Ammonium Salts alone	1·110	26·2	0·77	0·384	2·96	1·462
Nitrate Soda alone	1·112	26·5	0·75	0·392	2·84	1·473
Ammonium Salts and Mixed Mineral Manure ..	1·104	25·6	1·02	0·319	4·00	1·246
Nitrate Soda and Mixed Mineral Manure	1·108	25·8	1·00	0·341	3·90	1·324

by season and manuring. Table V. (p. 18) illustrates these points for the artificial manure series, and Table VI. (p. 21) for the farm-yard manure series. For each separate period, and for the total periods of the experiments, the particulars given are—the average specific gravity of the tubers; the percentages of dry or solid matter, of mineral matter, and of nitrogen, in the fresh tubers, also the percentages of mineral matter, and of nitrogen, in the dry substance of the tubers.

1.—*Artificial Manure Series.*

Referring to the Table (V.), it is seen that not only without manure, but with each of the six descriptions of artificial manure, the tubers have a higher specific gravity over the second and third, than over the first period of four years. It will be remembered that during the second and third periods the Champion was grown instead of the Rock as previously, and also that the earlier seasons were upon the whole much wetter, and therefore more conducive to luxuriance and less to maturation.

In countries where the Potato is largely grown for the manufacture of starch or potato spirit, the specific gravity serves as an important indication of quality. The higher the specific gravity, the greater as a rule is the proportion of dry matter, and the greater the proportion of starch. Indeed, Tables are constructed for the calculation of the percentage of dry matter, and of starch, from the specific gravity of the tubers.

Consistently, the Table shows that, with the higher specific gravity of the tubers over the second and third periods, there was, in every case, a considerably higher percentage of dry or solid matter over those periods, indicating better maturation.

Another point usually coincident with relatively high maturity of produce, is a relatively low percentage of mineral, or ash-constituents; and the figures show, in the majority of cases, a lower percentage of mineral matter in the fresh tubers, and in every case a considerably lower percentage in the dry substance of the tubers, over the second and third periods, than over the first period.

A low percentage of mineral matter in the dry substance of a crop, especially in the case of ripened products such as grain, and corn generally, does not as a rule indicate a defective amount of mineral matter, but the greater formation of organic substance in proportion to the mineral matter taken up; by which, of course, the percentage of the mineral matter in the dry substance is reduced—in other words, there is more favourable maturation.

Thus, then, the results relating to specific gravity, and to the percentages of dry substance, and of mineral matter, are perfectly consistent with the known comparative characters of the produce of the different periods.

It is not so, at first sight, so far as the nitrogen is concerned. There is, in every case, a considerably higher percentage of nitrogen in the fresh tubers, and in every case but one a higher percentage in the

dry substance of the tubers, over the second than over the first period, and in every case, both in the fresh and in the dry tubers, a higher percentage still over the third period.

Now in the case of the cereal grains, as a rule the better they are matured the lower is their percentage of nitrogen; the explanation being that maturation means the greater formation of the non-nitrogenous substance—starch—under the favourable ripening climatic conditions; and thus the already accumulated nitrogen shows a lower proportion to it, that is, a lower percentage. The same thing happens, though in a less marked degree, even in the case of the maturation of the succulent roots; the more there is of sugar accumulated, the lower is the percentage of nitrogen.

It will be seen further on that, in the case of the potato, more than 80 per cent. of the total nitrogen of the tuber exists in the juice, that is not in the fixed or insoluble portion. It is, in fact, in a very large proportion still formative or migratory matter. Hence, too, it is easy to understand how it is, as the results show to be the case, that the percentage of nitrogen in the tubers bears a very direct relation to the supplies available to the plant within the soil.

Leaving the figures relating to the separate periods, the summary at the foot of the Table gives the average results, as to specific gravity and percentage composition, over the total period of twelve years, for the unmanured plot, and for each of the artificially manured plots, and in these the influence of manure on the composition is more directly indicated.

Comparing the first and second columns with one another, it is seen at a glance that there is, with high specific gravity, high percentage of dry matter; and *vice versâ*. The produce without manure, and with purely mineral manure, that is to say with the least luxuriance, and consequently the earliest maturity, there is the highest specific gravity, and the highest percentage of dry substance in the tubers. With the nitrogenous manures alone, and very restricted growth, there is lower both specific gravity and percentage of dry matter; and, lastly, with both nitrogenous and mineral manures, and the greatest luxuriance, and imperfect maturity, there is the lowest specific gravity, and the lowest percentage of dry matter in the tubers.

Comparing one plot with another, the percentages of mineral matter and of nitrogen, whether reckoned on the fresh tubers, or on the dry substance, are seen to have no direct relation, either to the specific gravity, or to the percentages of dry matter, but to have a very direct relation to the supplies by manure; and when it is considered how large a proportion of both of these exists in the juice, or, so to speak, in a still formative and comparatively unfixed condition, the fact that their amount in the tubers bears so direct a relation to their supply becomes at once intelligible.

Thus, without manure, there is a comparatively low percentage of mineral matter, and a medium percentage of nitrogen. With mineral manures alone there is the highest percentage of mineral matter, and

by far the lowest percentage of nitrogen. With purely nitrogenous manures there is the lowest percentage of mineral matter, and the highest percentage of nitrogen. Lastly, with both mineral and nitrogenous manures together, there are intermediate percentages, both of mineral matter and of nitrogen, in the tubers.

2.—*Farm-yard Manure Series.*

TABLE VI.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Mean percentage Composition of the *Good* Tubers; 12 years, 1876-1887.

	Specific gravity of the Tubers.	Per cent. in Fresh Tubers.			Per cent. in Dry Matter.	
		Dry Matter.	Mineral Matter (Ash).	Nitrogen.	Mineral Matter (Ash).	Nitrogen.
Unmanured, 12 Years. (Plot 1.)						
		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Averages 6 years, 1876-1881 ..	1·112	27·74	0·89	0·302	3·23	1·09
Averages 6 years, 1882-1887 ..	1·123	28·44	0·80	0·366	2·81	1·29
Averages 12 years, 1876-1887 ..	1·118	28·09	0·84	0·334	3·02	1·19
Farmyard Manure, 6 Years; Unmanured, 6 Years. (Plot 2.)						
Averages 6 years, 1876-1881 ..	1·106	25·78	1·00	0·241	3·91	0·93
Averages 6 years, 1882-1887 ..	1·124	28·45	0·86	0·355	3·03	1·25
Averages 12 years, 1876-1887 ..	1·115	27·11	0·93	0·298	3·47	1·09
Farmyard Manure and Superphosphate, 7 Years; Farmyard Manure alone, 5 Years. (Plot 3.)						
Averages 6 years, 1876-1881 ..	1·103	25·50	1·04	0·232	4·08	0·91
Averages 6 years, 1882-1887 ..	1·112	26·36	0·96	0·353	3·66	1·35
Averages 12 years, 1876-1887 ..	1·108	25·94	1·00	0·292	3·87	1·13
Farmyard Manure, Superphosphate, and Nitrate of Soda, 6 Years; Farmyard Manure alone, 6 Years. (Plot 4.) (*)						
Averages 6 years, 1876-1881 ..	1·098	24·34	0·93	0·306	3·83	1·26
Averages 6 years, 1882-1887 ..	1·110	25·89	0·94	0·372	3·64	1·44
Averages 12 years, 1876-1887 ..	1·104	25·11	0·93	0·339	3·73	1·35
Summary. Average 12 Years, 1876-1887.						
Unmanured	1·118	28·09	0·84	0·334	3·02	1·19
Farmyard Manure, 6 years; Unmanured, 6 years ..	1·115	27·11	0·93	0·298	3·47	1·09
Farmyard Manure and Superphosphate, 7 years; Farmyard Manure alone, 5 years	1·108	25·94	1·00	0·292	3·87	1·13
Farmyard Manure, Superphosphate, and Nitrate Soda, 6 years; Farmyard Manure alone, 6 years (*) ..	1·104	25·11	0·93	0·339	3·73	1·35

* The Superphosphate, but not the Nitrate, was applied in the seventh year, 1882.

Reference may be made more briefly to the specific gravity, and to the percentage composition, of the tubers of the farm-yard manure series, as recorded in Table VI. (p. 21).

The Table shows that there was in every case a higher specific gravity, in every case a higher percentage of dry matter, and in every case a lower percentage of mineral matter in the dry substance, over the second period than over the first. All three conditions indicate, therefore, better maturation over the later years.

The percentage of nitrogen is, on the other hand, in every case considerably higher over the second period, with, it will be remembered, lower amounts of crop, dependent partly on lower manuring, and partly on the conditions of season being on the average more favourable for maturation than for luxuriance. That the high percentage of nitrogen over the second period was due to deficient accumulation of starch, as the result of limitation of growth, and not to more total nitrogen being taken up, is obvious from the fact already shown, that there was, in two out of the three cases, less total nitrogen taken up per acre over the second period than over the first.

Owing to the difference in the manuring over the two periods, the average results for the twelve years, as given at the foot of the Table, are not of a very definite character; but they consistently show higher percentages of both mineral matter and of nitrogen, with relatively higher amounts supplied. Especially is the higher percentage of nitrogen very obvious in the produce of the plot to which nitrate of soda was applied during the first six years.

Upon the whole the results which have been given have consistently shown higher specific gravity, and higher percentages of dry matter, the better matured the produce. As between one set of seasons and another, they have also shown lower percentages of mineral matter in the produce of those of the best maturing conditions. But as between one condition of manuring and another, the percentages, both of mineral matter and of nitrogen, have been shown to have a very direct connection with the relative amounts of them supplied within the soil.

It was stated that this fact was no doubt connected with the further fact, that a very large proportion, both of the mineral constituents and of the nitrogen, of the tuber, exists in a still only formative condition in the juice.

Obviously, therefore, it will be of interest to consider such evidence as is at command, as to the comparative composition of the whole tubers, and of the juice, and as to the distribution of the several constituents in the insoluble matter, or so-called *marc*, and in the juice, respectively.

COMPOSITION OF THE WHOLE TUBERS, AND OF THE JUICE.

The upper division of Table VII. (p. 23) shows the percentages of dry matter, of mineral matter (both crude and pure ash), and of nitrogen, in the whole tubers, and in the expressed juice of the tubers,

from each of the ten differently manured plots. The results are, in each case, the averages for the produce of the first three years—1876, 1877, and 1878.

TABLE VII.

EXPERIMENTS ON POTATOES,

Grown year after year on the same land, Hoosfield, Rothamsted.

Composition of the tubers, and of the juice.

Mixed year samples; Seasons, 1876, 1877, and 1878.

		Unmanured.	Superphosphate of Lime.	Mixed Mineral Manure. (*)	Ammonium Salts (= 86 lbs. Nitrogen).	Nitrate Soda (= 86 lbs. Nitrogen).	Ammonium Salts and Mixed Mineral Manure.	Nitrate Soda and Mixed Mineral Manure.	Farmyard Manure. Alone.	Farmyard Manure. And Superphosphate.	Farmyard Manure. Superphosphate and Nitrate Soda.	Means.
Percentage Composition of the Tubers and of the Juice.												
Dry Matter	Tubers	27·6	24·7	24·5	23·0	24·5	24·3	24·5	24·8	24·4	23·4	24·6
	Juice	4·6	4·7	4·6	4·7	4·9	4·8	5·1	4·5	4·6	4·9	4·7
Ash (Crude)	Tubers	0·91	1·14	1·14	0·75	0·73	1·10	1·07	1·01	1·05	0·95	0·99
	Juice	1·10	1·38	1·39	0·93	0·87	1·26	1·28	1·21	1·23	1·13	1·18
Ash (Pure)	Tubers	0·90	1·13	1·13	0·74	0·71	1·07	1·05	0·99	1·03	0·93	0·97
	Juice	1·08	1·37	1·38	0·93	0·87	1·26	1·27	1·21	1·22	1·12	1·17
Nitrogen	Tubers	0·27	0·19	0·18	0·31	0·32	0·25	0·26	0·22	0·20	0·29	0·25
	Juice	0·27	0·22	0·21	0·36	0·38	0·27	0·29	0·24	0·23	0·33	0·28
Percentage Composition of the Pure Ash.												
Ferric oxide and Alumina	Tubers	0·40	0·30	0·32	0·50	0·56	0·43	0·37	0·35	0·37	0·41	0·40
	Juice	0·50	0·53	0·51	0·44	0·49	0·37	0·51	0·51	0·46	0·56	0·49
Lime	Tubers	2·16	1·55	1·56	2·77	2·42	1·64	1·50	1·53	1·45	1·63	1·82
	Juice	2·27	1·67	1·94	2·26	2·27	1·81	1·75	1·67	1·56	1·74	1·89
Magnesia	Tubers	3·62	3·37	3·45	3·17	3·85	3·54	3·92	3·48	3·31	3·72	3·54
	Juice	4·32	3·76	3·80	3·55	4·17	3·86	4·42	3·91	3·67	4·16	3·96
Potash	Tubers	55·94	58·52	58·21	55·54	53·87	58·79	58·21	58·27	58·52	57·59	57·35
	Juice	53·42	57·92	57·08	55·53	54·02	56·89	57·31	56·81	57·39	56·00	56·24
Soda	Tubers	0·19	0·32	0·53	0·19	2·89	0·02	0·09	0·06	0·12	0·78	0·58
	Juice	1·77	0·37	0·57	0·49	2·00	0·49	0·74	0·52	0·49	1·21	0·87
Phosphoric Acid	Tubers	14·83	13·00	12·86	12·20	13·03	11·19	11·96	12·86	12·14	12·35	12·64
	Juice	11·12	10·87	10·27	9·33	10·21	8·90	9·46	10·11	9·35	9·73	9·93
Sulphuric Acid	Tubers	8·77	5·72	6·21	8·31	7·35	5·53	5·89	5·87	5·95	6·20	6·58
	Juice	9·99	6·91	7·23	9·54	8·86	6·78	7·45	6·91	6·72	7·07	7·75
Chlorine	Tubers	5·37	4·76	4·79	9·53	4·28	7·34	2·84	7·27	8·05	4·76	5·90
	Juice	5·42	5·43	5·60	11·65	6·35	7·46	3·22	8·73	9·08	5·36	6·83
Carbonic Acid	Tubers	9·25	13·03	12·58	9·05	11·88	12·53	14·75	11·37	11·31	13·07	11·88
	Juice	12·16	13·63	14·17	9·67	12·90	15·02	15·77	12·69	13·23	15·27	13·45
Silica	Tubers	0·68	0·50	0·57	0·89	0·83	0·64	0·51	0·58	0·60	0·57	0·64
	Juice	0·25	0·13	0·09	0·16	0·16	0·11	0·09	0·11	0·10	0·11	0·13

(*) Superphosphate, and Sulphates of Potash, Soda, and Magnesia.

The lower division of the Table shows the percentage composition of the pure ash, of the tubers, and of the juice, respectively; propor-

tionally mixed samples of the ashes of the three years having been, in each case, made and analysed. The analyses were made by Mr. R. Richter, of Berlin.

The first three columns of the Table relate to the plots without nitrogenous manures—that is without any manure, with superphosphate alone, and with mixed mineral manure alone; the next four columns to the plots with artificial nitrogenous manures, without and with mineral manure in addition; and the last three to those with farm-yard manure.

It is seen in the upper division of the Table, that the percentage of dry substance in the tubers ranges from 27·6 per cent. in the unmanured produce, to only 23 per cent. with ammonium salts alone.

The percentage of dry matter in the expressed juice, ranges from 5·1 in that of the tubers grown by mixed mineral manure and nitrate of soda, and 4·9 in that of those by nitrate of soda alone, or nitrate of soda added to farm-yard manure—these being the conditions of the greatest luxuriance of growth—to 4·5 with farm-yard manure alone, 4·6 without manure, with the mixed mineral manure alone, and with farm-yard manure and superphosphate—these being conditions of comparatively early maturity. There is thus indication that the juice remains the richer the less matured the crop; in other words, that the juice includes a good deal of not finally fixed matter, which is, in fact, material for further maturation; or, like the starch itself, for the nutriment of the plant which would in natural course be grown from the tuber. It may here be stated that the juice, which shows the percentage composition recorded in the Table, generally constitutes not far from 80 per cent. of the fresh tubers.

Although the percentage of dry matter in the fresh juice ranges only about one-fifth as high as that in the fresh tubers, the lines recording the percentages of pure ash, uniformly show a higher percentage of it, that is of mineral matter, in the fresh juice than in the fresh tubers. This of course implies that there is a much lower percentage of mineral matter in the insoluble substance than in the juice. Indeed it will be seen further on that perhaps 85 per cent., or even more, of the total mineral constituents of the tubers, may exist in the juice. Then, again, there is a wide range of variation in the percentage of mineral matter, both in the fresh tubers, and in the fresh juice, according to the conditions of manuring; the variations in the case of the whole tubers being mainly due to those in the juice. We have in these facts further evidence of the less fixed condition of the constituents of the juice, and of the less essential occurrence of a considerable proportion of them.

Next as to the percentage of nitrogen: it is seen to range from 0·18 in the fresh tubers grown by mixed mineral manure alone, to nearly double, or 0·31 and 0·32 in those grown by nitrogenous manure alone. In the same cases it ranges in the fresh juice from 0·21 to 0·36 and 0·38; and when it is borne in mind that from 80 to 85 per cent. of the total nitrogen of the tubers may exist in the juice, it is obvious that the range of variation in its amount in the insoluble matter is comparatively

limited. Further illustrations will be given on this point presently.

Referring to the lower division of the Table, the last column shows, for the ten different conditions as to manuring, the average percentage of each of the mineral constituents in the ash of the whole tubers, and in that of the juice. It is remarkable how nearly identical is the percentage composition of the two descriptions of ash, and this fact indicates much more of selective action, and of essentialness of composition, in the juice, than is generally found in the more purely vegetative organs of plants—such as the leaves and stems. But, in judging of the significance of the figures, it has to be borne in mind that the ash of the juice which shows this percentage composition may constitute 80 to 85 per cent., or even more, of the total ash of the tubers—a fact, the bearing of which will be illustrated further on.

I will not refer to much of the detail given in the other columns. It will suffice to call attention to the variations in the percentages of some of the more important constituents—potash and phosphoric acid for example—according to the conditions of manuring.

Thus it is seen that the percentage of potash ranges relatively high where the supply of it is relatively liberal, as for instance with the purely mineral manures, with the farm-yard manure, and with the nitrogenous and mixed mineral manures together. It is, on the other hand, relatively low without manure, and with the purely nitrogenous manures. Further, there is generally a somewhat corresponding tendency in the percentage in the ash of the juice, and in that of the whole tubers, a large proportion of the latter consisting of that of the former. Then it is to be observed, that where there was deficiency of potash in the supply, and in the ash, there is generally an increased percentage of lime in the ash, doubtless derived from the resources of the soil itself.

Next as to the phosphoric acid, its percentage is not so uniform as that of the potash. It is, under every condition of manuring, higher in the ash of the whole tuber than in that of the juice. On the other hand, the percentage of sulphuric acid is, in every case, higher in the ash of the juice than in that of the whole tubers. Lastly, in the ash both of the tubers and of the juice, when there is relatively high percentage of phosphoric acid, there is a general but not a uniform tendency to a relatively low percentage of sulphuric acid, and *vice versâ*.

Referring to the less essential constituents of the fixed formations, such as soda and chlorine for example, it may be observed that their percentage varies considerably, and is apparently very dependent on the supply within the soil.

CONDITIONS OF COMBINATION OF THE NITROGEN OF THE POTATO; AND THE DISTRIBUTION OF THE NITROGENOUS CONSTITUENTS IN THE SOLID MATTER, AND IN THE JUICE.

I now come to the very important question of the condition of combination of the nitrogen of potato tubers, and of the distribution of

the nitrogenous compounds, in the solid matter, and in the juice.

Table VIII. (below) shows the proportion of the total nitrogen of the tubers which exists as albuminoid or flesh-forming compounds, and the proportion which is in other forms. It also shows the proportion of the albuminoids which exist in the insoluble condition in the marc, and in the soluble condition in the juice. The upper division of the Table gives some results of *E. Schulze*, and the lower division results obtained at Rothamsted, on these points.

TABLE VIII.

Proportion of Albuminoid Nitrogen, and Non-Albuminoid Nitrogen, in Potatoes.

	Per cent. of the Total Nitrogen of the Tubers—			
	Albuminoid.			Non-Albuminoid. (*)
	In Marc.	In Juice.	Total.	
E. Schulze's Results.				
	Per cent.	Per cent.	Per cent.	Per cent.
No. 1	19·8	41·0	60·8	39·2
No. 2	13·5	46·2	59·7	40·3
No. 3	20·0	27·4	47·4	52·6
No. 4	14·0	34·2	48·2	51·8
No. 5	24·2	40·8	65·0	35·0
Mean ..	18·3	37·9	56·2	43·8
Rothamsted Results, 1878.				
Unmanured	15·8	48·7	64·5	35·5
Superphosphate	9·1	57·6	66·7	33·3
Mixed Mineral Manure	14·4	57·5	71·9	28·1
Ammonium Salts	12·3	45·1	57·4	42·6
Nitrate of Soda	11·0	40·8	51·8	48·2
Ammonium Salts and Mixed Mineral Manure ..	16·1	47·6	63·7	36·3
Nitrate of Soda and Mixed Mineral Manure ..	17·1	46·9	64·0	36·0
Farmyard Manure	22·0	45·9	67·9	32·1
Farmyard Manure and Superphosphate	19·5	49·8	69·3	30·7
Farmyard Manure, Superphosphate, and Nitrate of Soda	12·6	46·5	59·1	40·9
Mean	15·0	48·6	63·6	36·4

(*) Chiefly Amide.

It is seen that, of the total nitrogen of the tubers, Schulze found the amount existing as albuminoids in the insoluble matter to range from 13·5 to nearly double, or 24·2 per cent. of the whole, and to average only 18·3 per cent. In other words, on the average of the five experiments, 81·7 per cent. of the total nitrogen of the tubers existed in the juice.

In the Rothamsted experiments there was probably much greater variation in the conditions and characters of growth, than in those of Schulze; and we find a variation in the amount of the total nitrogen

of the tubers existing as albuminoids in the solid matter, from 9·1 to 22·0 per cent. of the whole; and the average to be only 15 per cent. The tendency of error of analysis would probably be to show too low an amount of the total nitrogen in the marc. However, the two sets of results sufficiently agree with one another to establish the fact that probably as a rule less than 20 per cent. of the total nitrogen will exist as insoluble albuminoids.

But the average of Schulze's results shows 37·9, and the average of the Rothamsted results 48·6 per cent. of the total nitrogen of the tubers, to exist as soluble albuminoids in the juice. In solid matter and juice together, therefore, Schulze's results show an average of 56·2 per cent., and those of Rothamsted of 63·6 per cent., of the total nitrogen of the tubers to exist as albuminoids; though from two-thirds to three-fourths of this may be in the juice.

On the other hand, Schulze's results show an average of 43·8, and those of Rothamsted of 36·4 per cent., of the total nitrogen of the tubers, to be in a non-albuminoid condition. By far the larger proportion of this non-albuminoid nitrogenous matter exists as amides, and much less as ammonia or nitric acid than is usual in the case of root-crops. The nutritive value of the non-albuminoid nitrogenous matters, which it is seen may amount to from one-third to perhaps nearly half of the total nitrogen of the tubers, is, however, to say the least, doubtful. Further, as two or three times as much of the albuminoid matter itself exists in the juice as in the insoluble portion of the tubers, it is probable that a considerable proportion, even of the albuminoid substance, will be lost as food. To this point I shall recur presently.

DISTRIBUTION OF THE CONSTITUENTS IN 1000 PARTS OF FRESH TUBERS.

It will be well now, disregarding the variations that may occur dependent on different conditions as to soil, season, manuring, and other circumstances, to endeavour to form a judgment as to the probable or approximate average composition of Potato tubers. Accordingly, Table IX. (p. 28) gives the estimated average composition of 1000 parts of fresh Potato tubers, and shows the probable distribution of the constituents, in the insoluble matter, and in the juice, respectively. The estimates are founded mainly on the average composition of the whole tubers, and of the juice, of the produce of the ten plots, over the first three seasons, 1876, 1877, and 1878, but partly also on other Rothamsted results, and on those of other experimenters.

The first column shows the estimated amounts of dry matter, nitrogen, total mineral matter (or ash), and of each ash-constituent, in 1000 of fresh tubers. The second and third columns show the distribution of the several constituents in the marc, and in the juice, respectively, of 1000 parts of the tubers.

The last two columns show, for 100 of dry matter, of nitrogen, and of ash, the proportion of each in the marc, and in the juice respectively.

They also show, for 100 of total ash in the tubers, the amount of each ash-constituent in the marc, and in the juice.

TABLE IX.

EXPERIMENTS ON POTATOES.

Hoosfield, Rothamsted.

Estimated average distribution of the constituents in 1000 parts of Fresh Tubers.

Constituents.	In Tubers.	In Marc.	In Juice.	Per cent. of total.	
				In Marc.	In Juice.
Dry Matter	246	209	37	85·0	15·0
Nitrogen	2·5	0·4	2·1	15·0	85·0
Ash { Crude	9·9	1·5	8·4	15·0	85·0
Ash { Pure	9·7	1·4	8·3	15·0	85·0
Ferric oxide and Alumina ..	0·04	0·00	0·04	0·00	0·41
Lime	0·18	0·02	0·16	0·21	1·63
Magnesia	0·35	0·02	0·33	0·21	3·36
Potash	5·58	0·88	4·70	9·43	47·90
Soda	0·06	(−0·01)	0·07	(−0·11)	0·71
Phosphoric Acid	1·23	0·40	0·83	4·29	8·46
Sulphuric Acid	0·64	0·00	0·64	0·00	6·52
Chlorine	0·57	0·00	0·57	0·00	5·81
Carbonic Acid	1·16	0·04	1·12	0·43	11·42
Silica	0·06	0·05	0·01	0·54	0·10
Total	9·87	1·40	8·47	15·00	86·32
Deduct O = Cl.. ..	0·13	0·00	0·13	0·00	1·32
Total	9·74	1·40	8·34	15·00	85·00

Directing attention first to the four upper lines of the Table, it is seen that 1000 parts of fresh Potato tubers are estimated to contain, on the average, 246 parts (or 24·6 per cent.) of total dry substance; 209 of which will be in the marc, and 37 in the juice. These amounts represent, as the last two columns of the Table show, 85 per cent. of the total solid matter to be in the marc, and 15 per cent. to be in the juice.

The amount and the distribution of the nitrogen is next shown. 1000 parts of the fresh tubers are estimated to contain 2·5 parts of nitrogen, or 0·25 per cent. Of this 2·5 parts, only 0·4 parts are estimated to be contained in the insoluble matter, and 2·1 parts in the juice. In other words, as the last two columns show, only about 15 per cent. of the total nitrogen of the tubers are supposed to be in the insoluble matter, and 85 per cent. in the juice.

The next two lines relate to the amount, and the distribution, of the mineral or ash constituents; the first of the two represents the amounts of crude ash as incinerated, and the second the amounts of pure ash, that is excluding any adventitious matter, such as sand and charcoal. As the individual mineral constituents are reckoned on the amount of pure ash, attention may be confined to the amount and distribution of it.

1000 parts of fresh tubers are estimated to contain 9·7 parts, or nearly 1 per cent. of pure ash. Of this, only 1·4 parts are supposed to be in the insoluble matter, and 8·3 parts in the juice—amounts corresponding to only 15 per cent. of the total pure ash in the insoluble matter, and 85 per cent. in the juice.

Thus, whilst of the total dry substance of the tubers 85 per cent. is reckoned to be in the insoluble matter, and only 15 per cent. in the juice; of the total nitrogen, and of the total mineral matter, only 15 per cent. is reckoned to be in the insoluble matter, and 85 per cent. in the juice.

Attention must now be briefly directed to the amount and the distribution of the individual mineral constituents in 1000 parts of the fresh tubers, as shown in the lower portion of the Table.

The ferric oxide and alumina are found in immaterial amount, and are probably mainly to be attributed to traces of adherent soil, not removed from the tubers in washing.

The lime, the soda, and the silica, are also in immaterial amounts, and the quantity of magnesia is also comparatively small. As already pointed out, the quantity of chlorine is very variable, and mainly dependent on the amount of the supply, whilst its occurrence is probably connected with its agency as a carrier of other constituents, rather than as an essential constituent in connection with any special function of the plant. Then there is the carbonic acid, which is probably in great part, the product of the destruction of organic acid in the incineration.

There remain the potash, the phosphoric acid, and, in a less degree, the sulphuric acid, as prominent mineral constituents of the tubers.

The Table shows that 1000 parts of the fresh tubers are reckoned to contain 5·58 parts of potash, 1·23 parts of phosphoric acid, and 0·64 parts of sulphuric acid.

It has been stated that potash is essentially connected with the formation of starch, and other non-nitrogenous matters, and phosphoric acid, and in some degree sulphuric acid, with that of the nitrogenous compounds. Yet we see that, of the 5·58 parts of potash in 1000 parts of tubers, only 0·88 parts exist in the marc, and 4·7 parts in the juice. A portion of that in the juice may, of course, be surplusage considered in relation to the transformations with which it is connected. But the fact that a much larger amount of the potash remains in the juice unassociated with the already formed and stored up starch, is of itself no evidence that it has not been of avail in the changes necessary to its formation; and the fact that the percentages of potash and phosphoric acid, and even of sulphuric acid, are so comparatively uniform in the ashes of the total tubers, and in those of the juice, and that they vary so little under such very various conditions of manuring, that is of their supply, would indicate that the amounts have some direct relation to the physiological changes within the organ, essential to its special formations.

Turning to the phosphoric acid, it is seen that of the 1·23 parts in

1000 of fresh tubers, 0·40 are reckoned to be in the marc, and 0·83 in the juice; or almost exactly one-third in the marc, and two-thirds in the juice. That there should be a considerable proportion of the whole of the phosphoric acid in the juice, seems quite consistent with the fact that so large a proportion of the albuminoid compounds exists in the juice. Indeed the average of Schulze's analyses shows almost exactly the same proportion of the total albuminoids to be in the juice—namely about two-thirds—as the estimates now under consideration show to be the case with the phosphoric acid.

Of the 0·64 parts of sulphuric acid in 1000 of fresh tubers, practically the whole is found in the juice.

The general conclusion to which these calculations as to the distribution of the various constituents of Potato tubers leads is—that from 80 to 85 per cent., or even more, of the total nitrogen of the tubers may be in the juice, and that about the same proportion of the total mineral matter also, may be in the juice. Further, that about the same proportion—80 to 85 per cent.—of the total potash, and about two-thirds of the total phosphoric acid, are in the juice. And when it is borne in mind that two-thirds, or more, of the nitrogen existing as albuminoids is in the juice, it is obvious that if the mode of cooking the Potato is such as to exclude the constituents of the juice from the final food product, there is considerable waste of nutritive matter; and that, indeed, the proportion of albuminoid matter in the food is exceedingly small. When Potatoes are used as a mere adjunct to an otherwise liberal diet, the general practice is to cut off the rind, and to put the peeled Potatoes into cold water, by which a large proportion of the soluble albuminoid matters must be washed out, before the temperature of the water becomes sufficiently high to coagulate and fix them. A very large proportion of the potash must also be washed out under such circumstances. When, however, potatoes constitute an important item in the diet, as in the rural districts of Ireland for example, it is usual to boil them in their skins—or, as is said, in their jackets. Under such circumstances, certainly a much larger proportion of the albuminoid matter will reach the stomachs of the consumers; and doubtless much more of the potash and phosphoric acid also. Still, it is obvious that a Potato diet must be very deficient in the proportion of nutritive nitrogenous compounds.

INCREASED PRODUCTION OF STARCH BY NITROGENOUS MANURES.

But although only about 15 per cent. of the total nitrogenous compounds of the tuber exists in the insoluble matter, and a very large proportion of the remainder—greater or less according to circumstances—is not available as flesh-forming material, yet Table IX. shows that 85 per cent. of the total dry or solid matter of the tuber may be in the insoluble matter or marc. The next question to consider is, therefore, of what does this consist? It has been incidentally stated that it consists chiefly of the non-nitrogenous substance—starch. It has further been

stated that the amount of starch may approximately be estimated from the specific gravity of the tubers, or from their percentage of dry substance. It has also been assumed that the increased amount of dry matter grown, per acre, under the influence of nitrogenous manures, consisted mainly of this non-nitrogenous substance. These various points are illustrated by the figures in the following Table (X).

TABLE X.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Estimates of Increase of Starch produced by Nitrogen in Manure. Average of 10 years, 1876-1885.

(Approximate Estimates.)

	Specific gravity of Tubers.	Dry Matter.		Starch.					
		Per cent. in Tubers.	Per Acre.	Estimated per cent. in Tubers.	Per acre.			For 1 Nitrogen in Manure.	
					In Produce.	In increase over Unmanured.	In increase over Mixed Mineral Manure.	In increase over Unmanured.	In increase over Mixed Mineral Manure.
		p. c.	lbs.	p. c.	lbs.	lbs.	lbs.		
Unmanured	1·116	28·0	1353	23·2	1120				
Mixed Mineral Manure	1·113	26·2	2384	21·9	1968				
Ammonium Salts	1·108	25·8	1419	21·4	1169	49		0·6	
Nitrate of Soda	1·111	26·2	1649	21·7	1362	242		2·8	
Mixed Mineral Manure and Ammonium Salts	1·103	25·3	4121	21·1	3436	2316	1448	26·9	16·8
Mixed Mineral Manure and Nitrate Soda	1·107	25·5	4069	21·2	3368	2248	1380	26·1	16·1

The Table shows, for the tubers grown without manure, and with the mixed mineral manure alone, with the nitrogenous manures alone, and the mixtures of mineral and nitrogenous manures, the average specific gravity over the ten years, 1876 to 1885, the average percentage of dry matter in the tubers, and total dry matter produced per acre. Next is shown the estimated percentage of starch in the tubers, calculated from the percentage of dry matter, by a factor arrived at by a consideration both of the rules of estimate of others, and of the results of calculations at Rothamsted, eliminating the other constituents.

As already fully illustrated, it is seen that high specific gravity of the tubers and high percentage of dry matter go together. The total amount of dry matter produced per acre, is considerably increased by the mineral manure alone, but very much more when the mineral and nitrogenous manures are used together. Thus, the produce of dry substance of tubers was, without manure 1353 lbs. per acre; with purely mineral manure 2384 lbs.; and with the mixture of the mineral and nitrogenous manures more than 4000 lbs. per acre.

The remaining columns show, the estimated percentage of starch in the tubers, the calculated total amounts of it per acre on the different plots, the increased amounts per acre over the amount without manure, under the influence of the nitrogenous manures, both when used alone, and in conjunction with the mineral manures; also the increased amounts over the produce with purely mineral manures, when both mineral and nitrogenous manures are used together. Finally, there is shown the increased amounts of starch produced by the use of 1 part of nitrogen in manure, reckoned both over the unmanured, and over the mineral manured produce.

It will be observed that the Potatoes are reckoned to contain on an average more than 21 per cent. of starch.

The produce of starch per acre is 1120 lbs. without manure, and 1988 or nearly 2000 lbs. with purely mineral manure—that is without nitrogen. The amount with purely nitrogenous manure is not so great as that with purely mineral manure. But with both nitrogenous and mineral manure, the quantity of starch is raised to an average of about 3400 lbs., or about $1\frac{1}{2}$ ton per acre.

The increased amount of starch over that without manure, produced by nitrogenous manures alone, containing 86 lbs. of nitrogen, is very small; only 49 lbs. when as ammonium salts; and 242 lbs. when as nitrate of soda. When both nitrogenous and mineral manures are used together, the increased amount of starch produced is more than 1 ton per acre—2316 lbs. with ammonium salts, and 2248 lbs. with nitrate of soda; but the increased amounts reckoned over the produce by the purely mineral manure, are only about two-thirds as much as when reckoned over the unmanured yield—namely, 1448 and 1380 lbs.

The last two columns show the increased amount of starch obtained for 1 of nitrogen supplied in the manure.

With the purely nitrogenous manures there is practically no increase in the amount of starch produced. When the two descriptions of manure are used together, there is, for 1 of nitrogen in manure, 26·9 and 26·1 parts, increased produce of starch reckoned over the unmanured produce, and 16·8 and 16·1 parts reckoned over the produce by the mixed mineral manure alone.

Here, then, in the Potato, we have a great increase in the production of the non-nitrogenous constituent—*starch*, by the use of nitrogen in manure, just as in the root-crops we have a great increase in the produce of the non-nitrogenous constituent—*sugar*, by the use of nitrogenous manure. There is, however, under corresponding conditions as to manure, somewhat more sugar produced in Mangel Wurzel for 1 of nitrogen in manure, than of starch in the Potato. Thus, with similar mineral manures, and the same amounts of nitrogen supplied, we had, reckoned over the produce by the mineral manures alone, in Mangel Wurzel 19·0 parts of sugar for 1 of nitrogen as ammonium salts, against 16·8 parts of starch in the Potato; and for 1 of nitrogen as nitrate of soda, we had 22·1 parts of sugar produced in the Mangel Wurzel, and 16·1 parts of starch in the Potato.

In the sugar-beet, however, there was even much more sugar produced for 1 of nitrogen—namely, when as ammonium-salts 28·6 parts, and when as nitrate of soda 36·0 parts.

As then the root-crops are essentially sugar-yielding crops, so the Potato is essentially a starch-yielding crop; and it is seen that, provided the mineral constituents are not deficient, the produce of both sugar and starch is greatly increased by the amount of nitrogen available to the plant within the soil, whether derived from previous accumulations, or from direct nitrogenous manuring.

This result, the greatly increased production of non-nitrogenous substances, by the use of nitrogenous manures, is equally striking in the case of cereal crops. The most prominent effect of the use of nitrogenous manures to such crops, is the increased production of starch in the grain, and of cellulose in the straw. Indeed, it is chiefly for the increased production of the non-nitrogenous substances, starch, sugar, and cellulose, that our direct nitrogenous manures are used. And if we reckon, not the amount of nitrogen applied, but only the increased amount of it taken up by the growing vegetation, it is obvious that the amounts of non-nitrogenous substances produced for 1 of nitrogen so taken up, are very much greater than the estimates above referred to would indicate.

In my lecture last year, I showed how small was the proportion of the flesh-forming nitrogenous constituents, to the non-nitrogenous or specially respiratory and fat-forming constituents, in root-crops; and in the Potato the proportion is considerably smaller still. For whilst the percentage of total nitrogen is much the same in fresh Mangel Wurzel, or Swedish Turnips, as in fresh Potatoes, the fresh tuber contains twice, or more than twice, as much digestible non-nitrogenous matter as the roots. On the other hand, a larger proportion of the total nitrogen exists as albuminoid compounds in the Potatoes than in the root-crops.

CONDITIONS OF SEASON AND MANURING FAVOURING DISEASE.

Thus far I have treated of the conditions of growth, and of the composition, of Potato tubers; and it has been shown that both the growth and the composition are very characteristically influenced both by season and manuring, and, so far as manure is concerned, very specially by nitrogenous manures. Incidentally it has been shown that both the occurrence, and the development, of the disease are also very materially influenced by both season and manuring.

The well known fact that the characters of the season have much to do with the development of the disease was very conclusively borne out by the results adduced. It was seen that under every condition as to manuring, whether artificial or otherwise, there was, on the average, a very much larger proportion of diseased tubers over the first four, or generally wetter seasons, when moreover the "Rock" was grown, than over the subsequent seasons of, on the average, better maturing

conditions, but when also the "Champion" was grown. It is not without interest to observe, that there was such a very great reduction in the amount of disease over the later periods of the continuous growth of the crop on the same land; conditions which might be considered unfavourable for healthy growth. It should be stated, however, that every year fresh seed was procured from a distance.

Then, again, so far as the influence of manuring is concerned, it was seen that the proportion of diseased tubers was the least where there was no supply of nitrogen by manure; that is where there was the least luxuriance, and the most restricted growth, and with this, the ripening tendency early developed. On the other hand, it was where there was liberal supply of nitrogen, and the most luxuriant growth, that there was by far the greatest proportion of diseased tubers.

It is not within my province, nor am I competent, to pass any judgment on either the admitted, or the disputed points relating to the identity, the morphological characters, and the mode of development, of the fungus. But the investigations carried on at Rothamsted do throw some light on the conditions, both without and within the plant, under which the development of the fungus is the most favoured, and on the results of its growth on the chemical composition of the tubers.

The fact that wet seasons favour the development of the disease would seem, independently of any influence favouring the migration of the spores, to be largely dependent on the condition of succulence and activity engendered in the juice; and the fact that there is much less disease with restricted growth, and early ripening, may simply mean that, under such conditions of the tuber, there is in the juice a restricted supply of food for the fungus. At any rate it is under the contrary conditions—those in which the juice is relatively rich in nitrogenous and mineral matters—that the development of the disease is the most pronounced. It has to be borne in mind that, in the experiments under consideration, the occurrence of the meteorological conditions favouring the development of the disease, finds the tubers of the different plots in very different conditions, not only as to richness of juice due to supply by manure, but, owing to these very conditions, in very different states as to maturity, that is as to fixity of composition, or susceptibility to change. The question arises, therefore, how far the tubers of restricted development, and greater maturity, would have shown more susceptibility to the disease if the adverse meteorological conditions had prevailed at an earlier stage of their growth; or how far, if they had occurred later, the more luxuriant tubers would have suffered less. However this may be, certain it is that, when the unsuitable weather comes, those tubers suffer most which have the richest juice, and the least fixity of composition.

CHEMICAL CHANGES IN THE TUBERS, INDUCED BY THE DISEASE.

I now come to the question—what are the changes which the development of the disease induces in the chemical composition of the

tubers? We have only been able to devote attention to this subject in certain special and limited aspects, but the results which have been obtained are consistent and definite, so far as they go, and of considerable interest.

In the first place, the percentages of dry matter, mineral matter, and nitrogen, were determined in the good or well-grown tubers, in the small or imperfectly developed tubers, and in the diseased tubers, of most of the experimental plots, in each of the first three years of the experiments. The sugar was also determined by the polariscope, in the juice of the good and of the small Potatoes.

Next, in a considerable number of cases, the white and the dark portions of diseased Potatoes were carefully separated. Each of these was separately pressed, so as to obtain the juice, and the insoluble portion or marc, separately, for analysis. In the juice of each, the mineral matter and the nitrogen were determined. In all cases the sugar, by polariscope, was determined; and, in selected cases, the glucose already existing, and the total sugar in the juice, after conversion into glucose. Lastly, in the marc, both of the white and of the dark portions, the mineral matter, and in some cases the nitrogen, was determined.

The data were thus provided, in the first place for comparing the composition, in some important aspects, of the fully matured, of the immature, and of the diseased, whole tubers; also for the comparison of the composition of the insoluble portion, and of the juice, both of the white or incipiently diseased, and of the dark or fully diseased, portions of the diseased tubers.

Table XI. (p 36) shows the percentages of dry matter, mineral matter, and in many cases of nitrogen in the dry matter, of the good, the small, and the diseased whole tubers, from each of the ten differently manured plots, in each of the first three years of the experiments—1876, 1877, and 1878. It also shows, in each case, the percentage of sugar, as determined by the polariscope, in the juice of the good, and of the small Potatoes.

I do not propose to refer in detail to the results relating to the produce of individual plots, but only to call attention to the general and average character of the results.

Referring first to the percentages of dry matter, a glance at the columns shows that, in every case but one in 1876, in eight out of the ten cases in 1877, and in nine out of ten in 1878, there was a lower percentage of dry substance in the less developed small, than in the more matured, or so designated "good" tubers. Again, there was, over the three years, in every case but one, a considerably lower percentage of dry matter in the diseased than in either the good or the small Potatoes. This result must obviously be due either to acquisition of water, or to loss of dry or solid substance, under the influence of the disease.

The next columns, which show the percentages of mineral matter in the dry substance of the different descriptions of tuber, afford satisfactory evidence that there had been a considerable loss of solid organic substance.

TABLE XI.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Particulars of the Composition of the Good, Small, and Diseased Potatoes.

	Per cent. in Tubers.									Per cent. in Juice.	
	Dry Matter.			Mineral Matter in Dry.			Nitrogen in Dry.			Sugar by Polariscope.	
	Good.	Small.	Diseased.	Good.	Small.	Diseased.	Good.	Small.	Diseased.	Good.	Small.
First Season, 1876.											
	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.	p. c.
Unmanured	23·87	23·65	20·22	3·53	3·49	4·27	1·126	1·113	1·268	0·60	0·76
Superphosphate	23·50	22·85	18·42	4·72	4·86	5·73	0·844	0·961	1·622	0·43	0·57
Mixed Mineral Manure (*)	22·99	21·28	20·73	4·64	4·94	5·21	0·744	0·962	0·998	0·43	0·59
Ammonium Salts	22·10	22·29	18·62	3·67	3·70	5·24	1·501	1·493	1·655	0·48	0·55
Nitrate of Soda	22·00	21·49	19·00	3·59	3·84	4·48	1·486	1·510	1·764	0·46	0·60
Ammonium Salts and Mixed Mineral Manure	20·87	19·49	18·02	4·71	5·01	5·88	1·274	1·510	1·808	0·52	0·57
Nitrate of Soda and Mixed Mineral Manure	21·89	20·47	19·36	4·46	4·76	5·39	1·332	1·573	1·593	0·48	0·58
Farmyard Manure	23·42	22·01	20·78	4·11	4·20	4·64	0·954	1·026	1·118	0·57	0·69
Farmyard Manure and Superphosphate ...	23·45	22·32	20·46	4·27	4·56	5·01	0·814	1·010	1·110	0·58	0·62
Farmyard Manure, Superphosphate, and Nitrate of Soda	21·23	20·64	17·91	3·92	4·12	5·24	1·390	1·497	1·722	0·40	0·53
Mean	22·52	21·65	19·35	4·16	4·35	5·11	1·147	1·266	1·486	0·50	0·61
Second Season, 1877.											
Unmanured	33·03	27·47	25·01	3·17	3·28	3·61	0·914			0·49	0·97
Superphosphate	26·53	25·76	23·54	4·44	4·68	5·11	0·764			0·27	0·54
Mixed Mineral Manure (*)	26·76	24·64	22·79	4·52	4·85	5·35	0·778			0·25	0·37
Ammonium Salts	21·99	25·72	22·62	3·07	3·18	3·74	1·276			0·61	0·89
Nitrate of Soda	25·86	26·80	22·30	2·85	3·00	3·56	1·164			0·63	0·80
Ammonium Salts and Mixed Mineral Manure	28·44	23·72	22·20	4·33	4·90	5·63	0·951			0·23	0·47
Nitrate of Soda and Mixed Mineral Manure	27·27	24·36	22·89	4·26	4·85	5·49	0·961			0·49	0·50
Farmyard Manure	26·49	24·45	21·39	4·00	4·22	5·33	0·800			0·33	0·62
Farmyard Manure and Superphosphate	25·96	24·35	20·50	4·26	4·49	5·90	0·799			0·30	0·55
Farmyard Manure, Superphosphate, and Nitrate of Soda	27·21	24·25	23·10	3·90	4·14	5·04	1·107			0·29	0·63
Mean	26·95	25·15	22·63	3·88	4·16	4·88	0·953			0·39	0·63
Third Season, 1878.											
Unmanured	25·96	24·25	21·62	3·26	3·93	4·43	0·878			1·82	1·92
Superphosphate	24·08	22·90	19·86	4·74	5·28	6·93	0·684			1·42	1·30
Mixed Mineral Manure (*)	23·68	22·76	20·58	4·90	5·36	6·37	0·706			1·44	1·23
Ammonium Salts	24·88	24·10	19·64	3·12	3·26	4·15	1·246			1·57	1·42
Nitrate of Soda	25·47	23·93	21·56	2·64	3·37	3·41	1·281			1·60	1·88
Ammonium Salts and Mixed Mineral Manure	23·55	20·93	19·11	4·57	5·25	6·25	0·946			1·27	1·00
Nitrate of Soda and Mixed Mineral Manure	24·42	21·69	20·44	4·41	5·45	5·93	0·935			1·25	1·17
Farmyard Manure	24·36	22·48	20·39	4·20	5·05	5·21	0·857			1·20	1·93
Farmyard Manure and Superphosphate	23·76	22·11	18·22	4·35	5·05	5·92	0·864			1·29	1·77
Farmyard Manure, Superphosphate, and Nitrate of Soda	21·86	22·22	18·78	4·45	5·12	5·30	1·229			1·23	1·50
Mean	24·20	22·74	20·02	4·06	4·71	5·39	0·963			1·41	1·51

(*) Superphosphate, and Sulphates of Potash, Soda, and Magnesia.

Quite consistently with the illustrations which have been before adduced, there is, with one exception, a lower, and sometimes a considerably lower, percentage of mineral matter in the dry substance of the more matured "good" than in the less matured "small" tubers. But the point of special interest is, that there is in every case, in each year, a higher, and frequently a much higher, percentage of mineral matter in the dry substance of the diseased, than in that of the sound tubers.

Now, as the mineral matter is fixed, and not subject to loss or gain, it is obvious that its increased amount in relation to that of the dry substance means that there has been a loss of the organic substance of the tuber under the influence of the disease, by which the proportion of the mineral to the organic matter is necessarily increased. It is possible, however, that in some cases the percentage of mineral matter may be slightly too high, owing to the difficulty of thoroughly cleansing the diseased tubers from adherent soil.

The next question is—whether this loss of organic substance is chiefly of the nitrogenous, or of the non-nitrogenous, constituents of the tubers? The columns showing the percentages of nitrogen in the dry substance of the good, the small, and the diseased tubers, in the first season, 1876, afford evidence on this point. There is almost uniformly a lower percentage of nitrogen in the dry substance of the good than in that of the small tubers, and this again is quite consistent with what has gone before. But there is in every case a higher, and sometimes a much higher, percentage of nitrogen in the dry substance of the diseased than in that of the sound tubers. The conclusion is, that it is chiefly, if not exclusively, non-nitrogenous constituents that have been lost; the proportion of the nitrogenous to the non-nitrogenous constituents being thereby increased.

Before leaving Table XI., the average results given in the bottom line for each year may be quoted, in further illustration of the conclusions which have been drawn from a general view of the detailed figures.

Thus, in 1876, the average percentage of dry substance is, in the good tubers 22·52, and in the diseased tubers only 19·35; the average percentage of mineral matter in the dry substance is, in the good tubers 4·16, and in the diseased tubers 5·11. Thus there is, with the disease, a lower percentage of dry matter, and a higher percentage of mineral matter in the dry substance—the two results together showing that there has been a loss of organic substance. Then, again, the percentage of nitrogen in the dry substance is, in the good tubers 1·147, and in the diseased tubers 1·486, or higher in that of the diseased than of the good tubers.

In 1877, with a very different range of percentages with different characters of season, the average percentage of dry matter is, in the good tubers 26·95, and in the diseased tubers only 22·63; whilst in the dry substance itself the average percentage of mineral matter is, in the good tubers 3·88, and in the diseased tubers 4·88.

In 1878, with again a different season, the results are quite

accordant. Thus, the average percentage of dry matter is, in the good tubers 24·2, and in the diseased tubers only 20·02; whilst the average percentage of mineral matter in the dry substance is, in the good tubers 4·06, and in the diseased tubers 5·39.

The evidence is, therefore, consistent and conclusive, that coincidently with the development of the disease, there is a considerable loss of organic substance, and that the loss is chiefly, if not exclusively, of non-nitrogenous matter.

The last columns of the Table show that there is a small but appreciable amount of sugar determinable by the polariscope in the juice of the tubers; but, that there is generally, and on the average, somewhat less in that of the more matured "good" than in that of the small tubers. Further, the difference is the greater in the tubers of 1877, the season of the highest maturation of the three. The indication is, therefore, that the percentage of sugar in the juice diminishes with maturation.

FURTHER EVIDENCE AS TO THE CHANGES INDUCED BY THE DISEASE.

Table XII. (p. 39) gives a comparative view of the composition of the white or only partially diseased, and of the dark or more fully diseased portions of the affected tubers. The first eight columns relate to the composition of the juice, and the last four to that of the marc; that is, the solid residue remaining after the expression of the juice. For the first season, 1876, the results are given for only three plots; but for 1877 and 1878, for each of the ten plots. The analytical results are, however, in some important respects, more complete for the few plots of the first year. It will be convenient to refer first to the more numerous but less complete results for 1877 and 1878.

First as to the composition of the juice of the white, and of the dark, or more completely diseased portion of the tubers. The first two columns do not show uniformly more, or uniformly less, mineral matter in the juice of the dark, than in that of the white portion, but on the average nearly identical amounts. The irregularities are probably partly due to adventitious soil-matter, as before referred to, and this would affect the determinations in the dark, or more diseased portions, more than in those of the white portions.

The third and fourth columns show, however, that there is always very much less nitrogen in the juice of the dark than in that of the white portion—indicating that nitrogen has been appropriated by the fungus in the course of its growth.

The sugar determined by the polariscope is, each year, very much higher in the juice of the white portion of the diseased tubers, than in the juice of sound tubers. Thus, in 1876, there was, in the juice of the sound tubers (see Table XI., p. 36) an average of only 0·50 per cent. of sugar by the polariscope, but in the juice of the white portion of the diseased tubers there was an average of 1·307 per cent. In 1877 there was an average in the juice of the good tubers of only 0·39 per cent., and in

TABLE XII.

EXPERIMENTS ON POTATOES.

Grown year after year on the same land, Hoosfield, Rothamsted.

Particulars of the Composition of Diseased Potatoes.

	Per cent. in Fresh Juice.								Per cent. in Dry Marc.			
	Mineral Matter (Ash).		Nitrogen.		Sugar. By Polariscope.		Sugar. Total reckoned as Glucose.		Mineral Matter (Ash).		Nitrogen.	
	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.	White Portion.	Dark Portion.
First Season, 1876.												
Ammonium Salts and Mixed Mineral Manure		1·639	0·262	0·191	1·455	0·00			1·60	1·89	0·434	1·718
Nitrate of Soda and Mixed Mineral Manure	(2·084)	1·114	0·331	0·163	1·067	0·00			0·70	2·08	0·352	1·727
Farmyard Manure and Superphosphate	1·887	1·542	0·249	0·161	1·400	0·233			0·73	1·72	0·269	1·393
Mean	1·986	1·432	0·281	0·172	1·307	0·078			1·01	1·90	0·352	1·613
Second Season, 1877.												
Unmanured	1·152	1·238	0·253	0·126	1·74	0·75			0·586	1·361		
Superphosphate	1·644	1·856	0·181	0·139	1·25	0·40			0·832	1·524		
Mixed Mineral Manure (*)	1·648	1·783	0·171	0·103	1·04	0·19	1·786	(0·351)	0·900	2·011		
Ammonium Salts	1·065	1·172	0·302	0·170	1·04	0·82			0·868	1·168		
Nitrate of Soda		1·166	0·205	0·164		0·62			1·163	1·881		
Ammonium Salts and Mixed Mineral Manure	1·720	1·793	0·279	0·143	0·67	0·52			0·824	1·112		
Nitrate of Soda and Mixed Mineral Manure	1·658	1·612	0·279	0·148	1·05	0·42	1·893	0·539	0·995	1·258		
Farmyard Manure... ...	1·503	1·578	0·199	0·107	1·32	0·47			0·681	1·443		
Farmyard Manure and Superphosphate	1·520	1·419	0·209	0·098	0·83	0·34			0·673	1·221		
Farmyard Manure, Superphosphate, and Nitrate of Soda	1·485	1·485	0·238	0·153	1·25	0·39			0·912	1·217		
Mean	1·488	1·511	0·232	0·135	1·13	0·49	1·839	0·445	0·843	1·370		
Third Season, 1878.												
Unmanured	0·997	0·972	0·205	0·100	3·34	0·84	3·571	1·923				
Superphosphate	1·321	1·154	0·164	0·083	2·77	0·67	3·952	1·498				
Mixed Mineral Manure (*)	1·347	1·233	0·143	0·069	2·62	0·55	3·774	1·497				
Ammonium Salts	0·821	0·848	0·290	0·146	3·67	0·93	4·566	2·016				
Nitrate of Soda	0·698	0·767	0·319	0·134	2·87	0·60	3·788	2·293				
Ammonium Salts and Mixed Mineral Manure	1·188	1·160	0·198	0·074	2·03	0·33	3·125	1·462				
Nitrate of Soda and Mixed Mineral Manure	0·806	1·213	0·211	0·097	2·14	0·85	3·205	2·336				
Farmyard Manure... ...	1·100	1·066	0·170	lost.	2·48	0·45	3·497	1·377				
Farmyard Manure and Superphosphate	1·132	1·088	0·171	0·076	2·45	0·65	(3·164)	lost.				
Farmyard Manure, Superphosphate, and Nitrate of Soda	1·092	1·088	0·259	0·124	2·57	0·60	3·704	1·497				
Mean	1·050	1·059	0·213	0·100	2·69	0·65	3·635	1·766				

(*) Sulphates of Potash, Soda, and Magnesia, and Superphosphate.

that of the white portion of the diseased Potatoes of 1·13 per cent. And, again, in 1878, there was in the juice of the good tubers an average of 1·41 against 2·69 per cent. in the juice of the white portion of the diseased tubers.

The next point to observe is, that the sugar is always very much less in the juice of the dark portion, that is after the growth of the fungus; and, in the few cases in which the total sugar was determined, the reduction in the amounts of it in the juice of the dark portion is very marked; in 1877 from 1·839 to 0·445, and in 1878 from 3·635 to 1·766 per cent.

The evidence clearly points to the conclusion that in the incipient stages of the disease starch is destroyed and sugar formed. This may either serve directly as nutriment to the fungus, in the growth of which carbonic acid is evolved; or the sugar may itself be decomposed, evolving carbonic acid and other products, and hence the loss of non-nitrogenous organic substance.

If we now turn to the composition of the marc of the white and of the dark portions, as shown in the results relating to 1876 and 1877, it is seen that, in every case, there is a very much higher percentage of mineral matter in the dry substance of the dark portion, showing that it had been appropriated by the fungus, of which the dark matter chiefly consists.

As already said, the results show, in every case, very much less nitrogen in the juice of the dark than in that of the white portion, the conclusion being that the fungus had appropriated it in its growth.

Thus, in 1876, the average percentage of nitrogen was, in the juice of the white portion 0·281, and in that of the dark portion 0·172; in 1877, it was in that of the white portion 0·232, and in that of the dark portion only 0·135; and in 1878, the average percentage was in the juice of the white portion 0·213, and in that of the dark portion only 0·10 per cent.

The more complete results, but for the three plots only, in 1876, conclusively show that the nitrogen lost by the juice had been so appropriated in the growth of the fungus. The figures show, in the first place, that there is an average of 1·986 per cent. of mineral matter in the juice of the white, and of only 1·432 per cent. in that of the dark portions, or very much less in the juice of the dark part; that is after the withdrawal for the growth of the fungus. Next as to the nitrogen in the juice:—there is an average of 0·281 per cent. in that of the white or incipiently diseased portion, and of only 0·172 per cent. in that of the dark or more completely diseased—that is, much less after the growth of the fungus. Lastly, as to the juice:—the percentage of sugar as indicated by the polariscope is 1·307 in that of the white, and only 0·078 per cent. in that of the dark part.

That the less amount of both mineral matter and nitrogen in the juice of the dark portion is due to their having been taken up in the growth of the fungus is still more directly and conclusively shown by the results relating to the solid residue, or marc, remaining after the

expression of the juice—the solid residue of the dark part consisting largely of the fungus itself.

Thus, whilst the average percentage of mineral matter in the marc of the white portion is only 1·01, or not very different from that in the dry substance of the sound tuber, the percentage in the marc of the dark portion is 1·90 or nearly double; and, again, whilst the percentage of nitrogen in the dry solid matter of the white portion is only 0·352, in that of the dark portion it is 1·613, or several times more. It is thus clearly shown, therefore, that the nitrogen lost by the juice has been appropriated in the growth of the fungus.

To sum up the evidence as to the changes suffered by the tuber under the influence of the disease, it would seem that the first material change is the destruction of starch, and the formation of sugar, apparently partly cane sugar and partly glucose. There is a considerable loss of organic, and chiefly non-nitrogenous, substance. This may be due in part to the decomposition of the produced sugar, and the evolution of carbonic acid and other products. But, it is, perhaps, mainly due to the evolution of carbonic acid, as a coincident of the growth of the fungus deriving its nutriment from ready-formed organic substance; this being a characteristic action in the growth of these non-chlorophyllous plants.

Finally, as the disease progresses, a very large proportion of both the mineral matter and the nitrogenous substance of the tuber is accumulated in the fungus. This is more especially the case in regard to the nitrogen, and in this fact we have doubtless some explanation of the further fact to which I have prominently called attention—namely, that the disease develops much more in tubers grown by highly nitrogenous manures, and having a highly nitrogenous juice, than in those grown under contrary conditions.

I have thus directed attention to the facts which the investigation has brought to light, as to the conditions, both of season and manuring, under which the disease is more or less developed, and also those as to the changes which take place in the composition of the tubers under the influence of the disease. It will, perhaps, be thought that I have stopped short of the point of most practical interest—namely, the suggestion of means of prevention of the disease. I do not propose to offer any specific recommendations on this point. At the same time, I think it will be granted, that any contribution to a clearer understanding of the conditions, and of the result, must lead to a better understanding of the cause, and that this, in its turn, is at any rate an essential step towards means of mitigation or prevention.

SUMMARY.

I have now discussed, in considerable detail, the conditions, both of season and manuring, upon which the successful growth of the Potato depends, and the results may be very briefly summarised as follows. Although of course requiring a full available supply of

the mineral constituents within the soil, it has been seen that, these conditions being provided, the amount of produce is largely dependent on the available supply of nitrogen within the soil. In practice farm-yard manure is mainly relied upon. It is used in very large quantities per acre, and is sometimes supplemented by liberal dressings of artificial manures, both mineral and nitrogenous. The crop removes, however, a less proportion of the nitrogen of farm-yard manure than any other farm crop. It was seen that the most characteristic result of the increased growth under the influence of nitrogenous manures, was an increased production of the non-nitrogenous constituent—*starch*. It was shown, however, that for 1 of nitrogen supplied in manure, the increased amount of starch obtained in the Potato was less than the increased amount of sugar obtained in the Mangel Wurzel, and much less than that yielded in sugar-beet. It was further shown that although a larger proportion of the total nitrogen of the Potato is in the albuminoid condition than in the case of root-crops, yet from four-fifths to five-sixths, or even more, of the total nitrogen, and from two-thirds to three-fourths, or more, of the total albuminoids, of the tuber, may exist in the soluble condition in the juice; and it is obvious that in the usual mode of cooking the Potato for the table, most of this is lost as food.

Next it was shown that the disease, though largely dependent on season, developed much more in tubers grown by highly nitrogenous manures, and containing a juice rich in nitrogen, than under contrary conditions. Finally, it has been shown that a result of the disease is a destruction of starch, the formation of sugar, the loss of organic substance, and the growth of the fungus at the expense of the substance of the tuber.

YIELD OF POTATOES IN DIFFERENT COUNTRIES.

I propose, in conclusion, to call attention to such information as is available, as to the area devoted to the Potato, and the amount of the crop obtained, in the different divisions of the United Kingdom, and in a number of Foreign Countries.

Table XIII. (p. 43) gives the estimates, according to the "Agricultural Returns," of the area under the crop, the aggregate produce, and the average produce per acre, in 1884, 1885, 1886, and 1887, and the mean for the four years, for England and Wales, for Scotland, and for Ireland; also for Great Britain as a whole, and for the United Kingdom as a whole.

The figures show, that the area under the crop averaged over the four years, in England and Wales nearly 404,000 acres, and in Scotland about 153,000 acres, or not much less than two-fifths the area of England and Wales together. Over the same period, the average aggregate produce per annum was, in England and Wales rather over

2½ million tons, and in Scotland about 900,000 tons; or rather more than one-third as much as England and Wales, and over one-fourth of the total of Great Britain. It is further seen that, in Great Britain as a whole, the average area under the crop is about 557,000 acres, and the average aggregate produce rather more than 3,400,000 tons.

TABLE XIII.

POTATOES.

Area under the crop, aggregate produce, and produce per acre, in the United Kingdom. Four seasons, 1884 to 1887 inclusive.

	1884.	1885.	1886.	1887.	Average.
Area under the Crop.					
England	Acres. 401,201	Acres. 359,026	Acres. 363,782	Acres. 369,243	Acres. 408,758
Wales		40,711	40,499	40,570	
Scotland	163,847	148,994	149,690	149,839	153,090
Great Britain ...	565,048	548,731	553,961	559,652	556,848
Ireland	798,952	797,292	799,847	796,939	796,258
United Kingdom ...	1,364,000	1,346,023	1,353,808	1,356,591	1,355,106
Estimated Aggregate Produce.					
England	Tons. 2,756,395	Tons. 2,182,712	Tons. 2,111,862	Tons. 2,300,338	Tons. 2,515,159
Wales		212,269	214,791	282,268	
Scotland	986,808	803,523	841,110	982,288	908,432
Great Britain ...	3,743,203	3,198,504	3,167,763	3,564,894	3,418,591
Ireland	3,040,352	3,175,738	2,667,724	3,569,402	3,113,304
United Kingdom ...	6,783,555	6,374,242	5,835,487	7,134,296	6,531,895
Estimated Average Yield per Acre.					
England	Tons. 6·87	Tons. 6·08	Tons. 5·81	Tons. 6·23	Tons. 6·23
Wales		5·21	5·30	6·96	
Scotland	6·02	5·39	5·62	6·56	5·90
Great Britain ...	6·62	5·83	5·72	6·37	6·14
Ireland	3·81	3·98	3·34	4·48	3·90
United Kingdom ...	4·97	4·74	4·31	5·26	4·82

Ireland is seen to have an average area of nearly 800,000 acres under the crop, or not far from one-and-a-half time as much as Great Britain; whilst its aggregate produce is notably less than that of Great Britain.

The aggregate area under Potatoes in the United Kingdom is rather over 1½ million acres, and the aggregate produce is rather more than 6½ million tons of tubers.

Turning now to the average produce per acre, the lower division of the table shows, that England and Wales together are estimated to yield about 6¼ tons; Wales apparently yielding rather less than England. The average yield of Scotland is rather less than 6 tons per

acre. These together give about 6⅛ tons as the average yield of tubers per acre per annum in Great Britain.

For Ireland the estimates show an average yield per acre of less than 4 tons, against more than 6 tons in Great Britain. It may be mentioned that the yield per acre given for Ireland, where the Potato is still of great importance as a supply of food for the people, is less than twice as much as was obtained at Rothamsted, over twelve years in succession on the same land, without any manure; it is scarcely more than was obtained by mineral manure alone; and considerably less than two-thirds as much as was yielded by mineral and nitrogenous manures together. It is clear, therefore, that the condition of the land, the cultivation, and the treatment of the crop, are, in Ireland, much inferior to those in the rest of the United Kingdom.

Table XIV. (below) gives similar particulars for 13 foreign countries, arranged in the order of their highest average produce per acre. Wherever the records were available, the averages for five recent years are given; and in other cases the best data at command have been taken. In all cases, however, the Table shows for what years the averages are calculated.

TABLE XIV.

POTATOES.

Area under the Crop, Aggregate Produce, and Produce per acre, in different countries.

	Number of years.	Seasons.	Average area under the Crop.	Estimated Aggregate produce.	Average yield per acre.
			Acres.	Tons.	Tons.
Norway	3	1865, '70, '75	80,417	482,233 (†)	6·01
Belgium	6	1878-'83	492,412 (*)	2,794,497 (‡)	4·54
Holland	5	1880-'84	350,284	1,434,356 (†)	4·09
Italy	6	1875-'80	169,210	693,042	4·09
Australasia	5	1880-'84	97,877	370,649	3·81
Germany	5	1882-'86	7,119,291	23,633,011	3·31
Sweden	5	1881-'85	381,616	1,224,646 (†)	3·21
Russia in Europe	5	1883-'87	3,172,935 (‖)	6,713,187 (†)	2·93 (‖)
France	5	1880-'84	3,321,830	9,299,499 (†)	2·80
Austria	5	1881-'85	2,570,082	7,102,672 (†)	2·76
Hungary	5	1882-'86	1,006,147	2,618,321 (†)	2·62
Denmark	7	1881-'87	110,306 (‖)	316,547 (†)	2·59 (‖)
United States	5	1881-'85	2,197,877	4,139,313 (†)	1·87

(*) 1880 only. (†) Recorded in bushels, reduced to tons, reckoning 56 lbs. per bushel.
(‡) Average of seven years, 1880-'86. (‖) 1881 only. (ᵘ) 1872 only.

A glance at the Table shows that, as a rule, it is the countries of small area under the crop, and generally those of small total area, that stand at the head of the list, and show the highest yield per acre. Of these, Norway stands first, with an average of about 6 tons per acre, or rather less than Great Britain. Belgium comes next with an average of little more than 4½ tons, or about three-fourths as much as Great Britain. Then come Holland and Italy, with little over 4 tons per acre, or scarcely two-thirds as much as Great Britain.

Turning now to some of the larger countries, with larger areas under the crop, it is seen that Germany, where the Potato is much

grown as an industrial crop, has an area devoted to it about thirteen times as large as in Great Britain, and yields about seven times the aggregate crop. But its average yield per acre is only 3·31 tons, or little more than half as much as that of Great Britain.

Then there is France, which, compared with Great Britain, has about six times the area under the crop, but yields less than three times as much aggregate produce, and gives considerably less than 3 tons per acre; that is, less than half as much per acre, as Great Britain, and even considerably less than Ireland.

Russia in Europe, again, according to the data, which are, however, incomplete and discordant, has, compared with Great Britain, nearly six times the aggregate area under the crop, but yields scarcely twice the aggregate produce; and, like France, yields less than 3 tons per acre; that is less than half as much as Great Britain.

Lastly, the United States, with nearly four times the area under the crop, but only about 1¼ time as much aggregate produce as Great Britain, yields an average of less than 2 tons per acre, or less than one-third as much as Great Britain.

Here, then, of 13 countries where the Potato is largely grown, their aggregate area under the crop being about 21 million acres, and their aggregate produce about 61 million tons, there is not one that reaches the average produce, per acre, of Great Britain. Norway, Belgium, and Holland, the most nearly approach our yield; and it is of interest to observe that these, and Denmark, are the countries that most nearly approach the United Kingdom in yield per acre of wheat and barley also.

It is, then, only the countries of small total area, and of small area under the crop, that at all nearly equal us in yield per acre; and among them, Belgium and Holland, the second and third on the entire list, more nearly approach us than any other, in *density of population*, and in *the amount of live-stock kept per acre*, and consequently in the supply of *manure*. Both these countries, too, have good home markets, besides their exports of agricultural produce.

It will be said, perhaps, that the better yield of potatoes per acre in Belgium than in most of the other countries, is due to the prevalence of peasant proprietors and small holdings; but, if this be so, how is it that it still yields only about three-fourths as much as Great Britain? Then, again, Germany yields per acre, little more than half as much potatoes, and only about two-thirds as much of either wheat or barley—and France less than half as much potatoes, and less than three-fifths as much wheat or barley—as Great Britain.

G. H. HARMER, PRINTER, WILTS AND GLOUCESTERSHIRE STANDARD OFFICE, CIRENCESTER.

14.

THE HISTORY

OF A

FIELD NEWLY LAID DOWN

TO PERMANENT GRASS.

BY

SIR J. B. LAWES, BART., LL.D., F.R.S.

FROM THE
JOURNAL OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND,
VOL. XXV.—S. S. PART I.

Printed by
SPOTTISWOODE & CO., NEW-STREET SQUARE, LONDON.
1889.

THE HISTORY

OF A

FIELD NEWLY LAID DOWN TO PERMANENT GRASS.

Contents.

	PAGE		PAGE
Introduction	3	Changes within the Soil in the Formation of the Meadow .	11
The Economical Results . .	4	The Botany of the Meadow .	23
Constituents supplied in the Manures and removed in the Crops	7	Summary and General Conclusions	26

Introduction.

THE history of a field laid down to permanent grass nearly thirty years ago, which has been mown for hay every year from the commencement, and of which the particulars, both of the manures applied and of the produce removed, have been recorded for the last twenty-three years, cannot fail to be of interest; especially at the present time, when the subject of permanent grass is receiving so much attention.

The land in question forms part of the Rothamsted Estate, and it had previously been under arable culture. In 1856 about two acres were fenced off, and let to Dr. Gilbert, who wished to have some grass-land near his house. The soil is very similar to much of that of Rothamsted and the neighbourhood; the surface being a heavy loam, with a few feet of reddish-yellow clay subsoil mixed with flint stones, and chalk below. In some parts of the parish the subsoil flints are so abundant that they are sifted out and sold in large quantities for road-making, &c. It is probable that Dr. Gilbert's field has a more gravelly subsoil than the portions of the farm at a higher level, and that it is, therefore, somewhat less suitable for permanent pasture. He decided to sell hay every year; and, as he kept no stock, he depended entirely upon purchased manures.

In 1856 barley, and grass seeds costing 32*s.* per acre, were sown. The standing crop of barley was sold by auction for 5*l.* 10*s.* per acre; but the grass seeds failed. Barley, and grass seeds to the same value, were again sown in 1857. The barley was sold by auction for 5*l.* 17*s.* 6*d.* per acre; but the grass seeds again failed. Red clover was sown in 1858. It yielded a small crop that year, which was made into hay and sold for 4*l.* 5*s.*, equal to 2*l.* 2*s.* 6*d.* per acre; and in 1859 the growing crop of clover was sold for 5*l.* per acre.

After the removal of the clover, grass seeds were again sown, and this time succeeded. In 1860 and 1861 artificial manures only were applied. It was found that under this treatment leguminous herbage was very scanty; and in 1862 some alsike and Dutch clover were sown, and a heavy dressing of dung, at the rate of 11 tons 17 cwts. per acre, was applied, with a little superphosphate and nitrate of soda in addition. In 1863 dung was again applied, at the rate of 4 tons 13 cwts. per acre; but in 1864 and 1865 artificial manures only, consisting of superphosphate, nitrate of soda, and a little sulphate of potash, were used.

The Economical Results.

From this time more attention was paid to the field. The object was to endeavour to maintain the character of the herbage, and at the same time to obtain as large crops of hay as was consistent with the maintenance of this condition. It was sought to maintain the quality by means of dung, and to secure full quantity by the use of artificial manures in addition, which consisted of superphosphate, and sulphate of potash, with guano, or nitrate of soda, or both, as nitrogenous manure. After the first few years the general plan adopted was to apply two or sometimes three trucks of London dung every other year, but occasionally it was applied only every third year; artificial manures were, however, with one or two exceptions, applied every year.

The following Table (I.) shows the amounts of dung and of the different artificial manures applied, also the amounts of hay removed, per acre, in each of the 23 years 1866–1888 inclusive; and the summary at the bottom gives the average amounts per acre per annum, both of manure applied and of hay sold, over the first 8 years 1866–1873, the second 8 years 1874–1881, and the third period of 7 years 1882–1888; also the average over the whole period of 23 years.

Referring here to the average results only, the figures in the bottom division of the Table show, that the amount of dung applied averaged 2 tons 10 cwts. per acre per annum over the

TABLE I.—MANURES APPLIED AND HAY REMOVED PER ACRE PER ANNUM.

Year	Manures applied					Produce of hay
	Dung	Super-phosphate	Sulphate of potash	Guano	Nitrate of soda	
	tons cwts.	lbs.	lbs.	lbs.	lbs.	tons cwts.
1866	—	64	64	64	64	1 10¼
1867	—	64	64	64	64	1 6¼
1868	6 12	—	—	128	128	1 1¼
1869	—	—	—	201	—	1 16½
1870	6 4	—	—	—	134	0 11¾
1871	—	—	—	67	67	1 13¾
1872	—	67	—	—	134	1 18¾
1873	7 4	—	—	—	—	1 4
1874	—	201	67	—	134	1 13¾
1875	6 18	134	—	—	134	1 11
1876	—	101	101	—	168	1 14¾
1877	8 11	67	67	—	134	2 1¾
1878	—	101	84[1]	—	168	1 10¾
1879	7 1	67	67	—	101	2 9¾
1880	—	67	67	67	67	1 8¾
1881	7 14	67	67	—	134	1 0¾
1882	—	67	67	—	134	2 11¼
1883	8 8	67	67	—	67	2 2¼
1884	—	67	67	—	67	2 0¾
1885	9 6	67	67	—	67	2 12¾
1886	—	67	67	—	67	2 5¼
1887	10 8	—	—	—	—	1 13½
1888	—	67	67	—	67	1 16¼
Summary—Averages.						
8 years 1866–1873	2 10	24	16	66	74	1 8
8 years 1874–1881	3 16	101	65	8	130	1 13¾
7 years 1882–1888	4 0	57	57	0	67	2 3¼
23 years 1866–1888	3 8	61	46	26	91	1 14⅜

first 8 years, 3 tons 16 cwts. over the second 8, 4 tons over the last 7 years, and 3 tons 8 cwts. over the 23 years. That is to say, there was a gradual increase in the amount of dung applied. Of artificial manures there was an increase, both of the mineral and of the nitrogenous, over the second period compared with the first; but there was again a reduction over the third period. It was found that, under the condition provided by the dung, aided by the artificial mineral manures, the application of as much as 1 cwt. of nitrate of soda per acre per annum was liable to give a too stemmy, and almost exclusively grassy herbage.

[1] 336 lbs. of kainit were applied, reckoned to contain about 84 lbs. sulphate of potash; and it would also supply sulphate of magnesia, and chlorides of magnesium and sodium.

Hence the quantity was reduced, until it is now found that, with the amount of dung and of artificial mineral manures used, about two-thirds of a cwt. of nitrate of soda per acre per annum is sufficient to yield as full a crop as can be obtained without reducing the bottom herbage, and therefore the quality of the hay.

It is seen that, under the above conditions as to manuring, the amount of crop has increased from an average of 1 ton 8 cwts. per acre per annum over the first 8 years, to nearly 1 ton 14 cwts. over the second 8 years, and to nearly 2 tons 4 cwts. over the third period of 7 years; the average over the 23 years being 1 ton 14⅝ cwts. of hay per acre per annum.

It is obvious, therefore, that the condition of the land has gradually improved. It may be added that, in 1888, in consequence of the luxuriant second growth, a second crop was, for the first time, taken. It amounted to 1 ton 4¼ cwts. per acre, and the first and second crops together amounted to 3 tons 1 cwt. Purchased dung, at the rate of 9 tons per acre, has, however, since been applied. The amount of the second crop is not included in the record of produce given in Table I., which relates to first crops only.

TABLE II.—BALANCE SHEET.

Average per acre per annum, 23 years, 1866–1888.

	£	s.	d.
3 tons 8 cwts. purchased dung, including carriage, cartage, and spreading, at 7*s.* 6*d.* per ton	1	5	6
61 lbs. superphosphate, at 5*s.* per cwt.	0	2	9
46 lbs. sulphate of potash, at 15*s.* per cwt.	0	6	2
26 lbs. guano, at 11*s.* per cwt.	0	2	6
91 lbs. nitrate of soda, at 16*s.* per cwt.	0	13	0
Total for manures	2	9	11
Rent (as arable), tithe, and rates	1	10	0
Harrowing, rolling, and occasional labour	0	10	0
Total	4	9	11
1 ton 14⅝ cwts. of hay sold, at 4*l.* per ton	6	18	6
Balance	2	8	7

In attempting to make out a balance-sheet of the results, it is impossible to be strictly accurate, owing to the number of years over which the operations have extended, and the great fluctuations which have taken place in the prices both of the manures used and of the produce obtained during the period. As to the expenses of hay-making, they may be considered as set against the rent obtained for feeding the after-grass, as this fully or more than paid the cost. Adopting an average price of 4*l.* per ton for the hay, of 7*s.* 6*d.* per ton for the dung spread on the

land, which is as nearly as possible the average of the actual cost, and taking the artificial manures at about the average price actually paid, which, however, is higher than they can be purchased for at the present time, Table II. (page 6) gives the estimated outlay and money return per acre per annum over the whole period.

It is obvious, from the results given in Tables I. and II., that a good permanent grass field has been formed from this arable soil, not only without loss, but with some profit. Much of the success is doubtless due to the purchased town dung, and to the comparatively little cost of cartage, owing to the proximity to the railway station, which is only about half a mile distant.

Constituents supplied in the Manures, and removed in the Crops.

It will be desirable, in the next place, to endeavour to arrive at an estimate of the amounts of some of the more important constituents supplied in the manures, and removed in the crops.

With regard to the composition of the dung applied, we have to found an estimate from a consideration of the composition of ordinary farmyard manure, and of the difference in the conditions of the production of such manure and of that obtained from town stables.

In our estimates of the average composition of farmyard manure, we have taken into consideration the results of actual analyses made by Boussingault and by the late Dr. Voelcker; and we have also calculated the composition of such manure on the basis of the quantity of straw and of foods which, in an ordinary four-course rotation, with some import of cake, will go to make up a yard of dung. The estimate so arrived at is, moreover, controlled by actual analyses of good box dung, made in experiments at Woburn many years ago.

Of purchased town dung, however, so far as we are aware, no analyses have been made. It might be argued that, as straw is expensive, town manure would be richer in excrementitious matters than farmyard manure. On the other hand, the smaller quantity of straw used would allow more of the liquid manure to pass into the drains. It may also be observed that maize, which is so largely used as horse food in towns, contains less nitrogen, and less phosphoric acid and potash, than the average of the cake and corn used as food on the farm. Further, whilst the greater part of the farmyard manure is produced by animals which live in the sheds, or boxes, or yards, and deposit the whole of their excrements there, the horses in towns are out of

the stable for some hours daily. Upon the whole, therefore, there does not seem to be conclusive ground for supposing that town dung is very much richer than ordinary farmyard manure.

So far as the nitrogen is concerned, however, the estimates given below are based on the same percentage as we assume for farmyard manure, namely 0·64; and also on the alternative assumption of 0·80 per cent. In reference to this point it may be added that the average of determinations made at Rothamsted, in eight samples of box-dung made at Woburn, was 0·736 per cent.

Table III. (opposite) gives approximate estimates of the amounts of nitrogen, phosphoric acid, and potash, in the manures applied, and in the crops removed, assuming average percentages of those constituents in the manures and crops as follows:—Percentage of nitrogen: in the dung 0·64 or 0·80, in the guano 12·0, in the nitrate of soda 15·5, and in the hay 1·5. Percentage of phosphoric acid: in the dung 0·23, in the superphosphate 16·0, in the guano 12·0, and in the hay 0·4. Percentage of potash: in the dung 0·53, in the sulphate of potash 50·0, in the guano 2·5, and in the hay 1·6.

First as to the *nitrogen*:—It is seen that, even adopting the lower percentage of nitrogen in the dung, the calculations show more nitrogen supplied in the manures than removed in crops over the first, the second, and the total periods, but rather less over the third period. The details show that the amount of nitrogen supplied in the dung was higher in each succeeding period; but that supplied in artificial manures was only about half as much over the third as over either of the preceding periods; whilst the amount removed in the crops gradually increased from 47 lbs. per acre per annum over the first period, to 57 lbs. over the second, and 72·4 lbs. over the third period. Nevertheless, as already said, there is, over the total period of 23 years, an excess of nitrogen supplied in manure, which, as the Table shows, amounted to an average of 7·9 lbs. per acre per annum.

Adopting the higher percentage of nitrogen in the dung, however, there is an excess supplied in manure, compared with that taken off in crops, over each of the three periods; and the excess amounted to an average of about 20 lbs. (20·1), per acre per annum, over the 23 years.

Next as to the *phosphoric acid*:—The estimates show an excess supplied in the manure over that taken off in crops, over each of the three periods, and an average excess of 14·9 lbs. per acre per annum over the 23 years. In fact, over each individual period, and the total period, the dung alone is esti-

TABLE III.—NITROGEN, PHOSPHORIC ACID, AND POTASH, SUPPLIED IN THE MANURES, AND REMOVED IN THE HAY-CROPS.

Quantities per Acre per Annum.

	Per acre per annum			
	Nitrogen			
	At 0·64 per cent. in dung	At 0·80 per cent. in dung	Phosphoric acid	Potash
8 *years*, 1866–1873.				
	lbs.	lbs.	lbs.	lbs.
In dung	35·8	44·8	12·9	29·7
In superphosphate	—	—	3·8	—
In sulphate of potash	—	—	—	8·0
In guano	7·9	7·9	7·9	1·6
In nitrate of soda	11·5	11·5	—	—
Total	55·2	64·2	24·6	39·3
In hay removed	47·1	47·1	12·5	50·2
More (+), or less (−), in manure than in crops	+8·1	+17·1	+12·1	−10·9
8 *years*, 1874–1881.				
In dung	54·1	67·7	19·4	44·8
In superphosphate	—	—	16·2	—
In sulphate of potash	—	—	—	32·5
In guano	1·0	1·0	1·0	0·2
In nitrate of soda	20·2	20·2	—	—
Total	75·3	88·9	36·6	77·5
In hay removed	57·0	57·0	15·2	60·8
More (+), or less (−), in manure than in crops	+18·3	+31·9	+21·4	+16·7
7 *years*, 1882–1888.				
In dung	57·6	71·9	20·7	47·7
In superphosphate	—	—	9·1	—
In sulphate of potash	—	—	—	28·5
In guano	0	0	0	0
In nitrate of soda	10·4	10·4	—	—
Total	68·0	82·3	29·8	76·2
In hay removed	72·4	72·4	19·3	77·2
More (+), or less (−), in manure than in crops	−4·4	+9·9	+10·5	−1·0
***Total period*—23 *years*, 1866–1888.**				
In dung	48·8	61·0	17·5	40·4
In superphosphate	—	—	9·8	—
In sulphate of potash	—	—	—	23·0
In guano	3·1	3·1	3·1	0·7
In nitrate of soda	14·2	14·2	—	—
Total	66·1	78·3	30·4	64·1
In hay removed	58·2	58·2	15·5	62·1
More (+), or less (−), in manure than in crops	+7·9	+20·1	+14·9	+2·0

mated to supply more phosphoric acid than was removed in the crops; and, taking the dung and artificial manures together, there was, taking the average of the whole period, nearly twice as much supplied in manure as removed in the crops.

Lastly, as to the *potash*:—It was only over the second period, when the largest amount of artificial potash-manure was employed, and when the hay crops had not reached their maximum, that the calculations show an excess of potash supplied in manure. Over the first period there was a considerable, and over the third period there was a slight, deficiency of supply. It is further of interest to observe that over neither period was the dung alone estimated to supply anything like the amount of potash removed in the crops; whilst over the whole period it did not supply two-thirds as much as was removed in the hay. Taking the whole period of 23 years, there is, in dung and artificial manures together, an average of only 2 lbs. more potash supplied per acre per annum than was taken off in crops.

The calculations show, therefore, that the manures supplied considerably more nitrogen and phosphoric acid, but only about as much potash, as the crops removed.

It is seen that the estimates for the whole period show an average of 58·2 lbs. of nitrogen, 15·5 lbs. of phosphoric acid, and 62·1 lbs. of potash, removed in the crops, per acre per annum. On this point it may be stated that the Rothamsted experiments on the continuous growth of grass without manure have shown that, in first crops of hay alone, more than 30 lbs. of nitrogen, and nearly 30 lbs. of potash, are, on the average, annually removed in the crops so grown for many years in succession on the Rothamsted soil; and it is to be supposed that something like these amounts would be available to the growing grass crops under consideration.

Upon the whole, it may be concluded that, under the conditions of manuring provided, there would be accumulation within the soil both of nitrogen and phosphoric acid, though but little, if any, of potash. Indeed, the results afford a forcible illustration of how great is the exhaustion of potash when hay is sold, and how important it is that there should be adequate return either in dung or in artificial manures.

It has to be borne in mind, however, that whilst neither phosphoric acid nor potash is subject to any appreciable or material loss by drainage, the nitrogen of manures is subject to such loss. In the case of artificial nitrogenous manures, such as ammonia-salts and nitrate of soda, the loss may sometimes be very considerable when they are applied to arable land, when there is no crop actively growing, and in wet seasons when

there is much drainage. Under similar conditions, there may also be more or less loss from the soluble nitrogenous portion of dung. It is probable, however, that, in the case of the mixed herbage of grass-land, with a great variety of plants, having widely different root-ranges and habits of growth, and with vegetation going on to a greater or less extent almost the whole year round, there will be much less loss of nitrogen by drainage, even from artificial manures, than when they are applied to arable land—especially when such small quantities are used, and at the commencement of the active growth of the season, as in the case now under consideration; whilst it may be doubted whether there will generally be any material loss of nitrogen by drainage from farmyard manure or town dung applied to grass-land. But when dung is applied in excessive quantities to arable land, or to soil which becomes water-logged and is not sufficiently aërated, there may be more or less loss by the evolution of free nitrogen.

Changes within the Soil in the Formation of the Meadow.

Before discussing the experimental results obtained, relating to the changes which have taken place in the condition of the land during the formation of this particular meadow, it will be well to direct attention, in general terms, to the main distinctions between the soil of arable land and that of permanent grass.

If we examine arable land after the removal of a grain crop, we find that the amount of roots left in the soil is very small. Thus, in a case in which a large crop of barley had been grown, four samples of soil were taken, each 12 inches square and 9 inches deep, and from each the roots were very carefully separated. The calculation of the results showed an average of only 536 lbs. of roots per acre in the surface-soil to the depth of 9 inches. Of above-ground residue, or stubble, there was on the average 1,104 lbs. per acre. The nitrogen in the stubble and in the roots of the surface-soil, taken together, amounted to only about 8½ lbs. per acre. Where, in the same field, clover had grown, there was, on the other hand, an average of 3,107 lbs., or nearly 1 ton 8 cwts. of roots per acre, in the first 9 inches of depth; and there was 2,669 lbs., or nearly 1 ton 4 cwts., of above-ground residue; and the nitrogen in the two together was more than 90 lbs. per acre. There was, besides, a greater amount of roots, and of nitrogen in them, in the second and third 9 inches than in the case of the barley-ground.

When land is laid down to permanent grass the seeds are more frequently sown with barley than with any other crop; and after a certain number of years, greater or less according to

soil and treatment, when the meadow may be said to be formed, it is found that the soil contains very much more vegetable matter—amounting, in fact, to many thousands of pounds per acre in the first 9 inches of depth. Thus, in the case of some of the experimental plots of the old grass-land at Rothamsted, samples have been taken to the depth of 9 inches, the whole of the above-ground growth having been first carefully cut off by scissors, and the vegetable matter remaining in the soil picked out by hand. The average of twenty-four such determinations indicated 16,601 lbs. (nearly 7½ tons) of vegetable matter per acre; and in one case the amount was 24,548 lbs., or nearly 11 tons per acre. The nitrogen in this residue amounted, on the average of the 24 samples, to about 125 lbs. per acre, and in the case of the maximum amount of residue, to about 180 lbs.

Again, the nitrogen in the first 9 inches of the soil of the barley-land above referred to, after the roots had been separated, amounted to 0·1416 per cent. in the fine dry soil, the average weight of which was about 2,600,000 lbs. per acre to the same depth; so that the amount of nitrogen in it would correspond to about 3,682 lbs. per acre. The nitrogen in the fine dry soil of the clover-land was 0·1566 per cent., which, reckoned on the same weight of surface-soil, corresponds to 4,072 lbs. per acre to the depth of 9 inches. On the other hand, the surface-soil of the old grass-land, which yielded the amounts of roots above referred to, indicated, for the average of the 24 samples, 0·2346 per cent. of nitrogen; but the weight of fine dry soil—that is, excluding stones, roots, and water—amounted to an average of only about 2,000,000 lbs. per acre to the depth of 9 inches. Hence the amount of nitrogen to that depth would be about 4,692 lbs., or much more than in the case of the clover-land, and very much more than in that of the barley-land, though with much less soil. The highest amount of nitrogen found in the surface-soil of any of the experimental grass plots was, however, 0·2737 per cent., corresponding to 5,474 lbs. of nitrogen per acre on a weight of 2,000,000 lbs.

With the increase of nitrogen, as the arable land is converted into meadow, there is also a considerable increase of carbon. Thus, in the surface-soil of the experimental grass-plots at Rothamsted, there are about 13 or 14 parts of carbon to 1 of nitrogen; whereas, in the case of the Rothamsted arable surface-soils, there are only from 10 to 11 parts of carbon to 1 of nitrogen, and in the subsoils much less. The relation of carbon to nitrogen in the surface-soil is, however, very much less than in the vegetation above it, and very much less than in the roots separated from it. Both the nitrogen and the carbon of the

soil have been derived from vegetable residue, partly of the manure applied, but in great part also of the crops grown; and it has undergone decomposition, and thereby lost most of its carbon, whilst what remains exists in more stable combination.

Such accumulations are retained in the soil with great tenacity, and they contribute to its fertility. From the unmanured plot of the Rothamsted permanent grass experiments, taking first and second cuttings together, 43 crops of hay have been removed during the last 33 years; but the greater part of the long previously accumulated fertility still remains. When, however, grass-land is broken up and converted into arable, the accumulated fertility rapidly diminishes.

When it is borne in mind that all our arable soils were originally covered with natural herbage or timber, and that during centuries of arable culture much of the previously accumulated fertility has thereby been removed, it will readily be understood that, in the re-conversion of such arable land into permanent grass, much of the used-up accumulated fertility must be restored, before we can get it back into a satisfactory condition.

Assuming these to be the general conditions essential for the conversion of arable into permanent grass-land, we may now endeavour to ascertain what changes have actually taken place in the soil, during the formation of the meadow, the history of which we have under consideration. Any estimate of the accumulations which have taken place can, however, only be approximately correct, since we have not any exact data on the important point of the amount of nitrogen which the soil contained when it was first taken in hand in 1856 as arable land.

But we have made some thousands of determinations of nitrogen in the surface-soils and subsoils of the Rothamsted experimental fields, which are very near to this newly formed meadow; and we are in a position, therefore, to make a fair estimate on the subject.

Careful samples were, however, taken in January 1879—that is, when no crop had been removed since the previous July—and again in September 1888, after a second crop of hay had been taken. It will be instructive to go into some detail as to the methods of experimenting adopted, and the results obtained, as the discussion will illustrate some of the difficulties which are encountered in endeavouring properly to interpret analyses of soils made on samples taken at different periods, and in different conditions of the land.

The plan adopted in taking the samples is, to drive down a steel frame, 12 by 12 inches, and 9 inches deep, open at top and bottom, until the upper edge is level with the surface of the soil. All above-ground vegetation is then cut off as closely as possible with scissors. The soil enclosed within the frame is then carefully removed, exactly to the depth of the frame, and immediately weighed. The soil is then partially dried, and submitted to mechanical separation by a series of sieves. All visible vegetable matter is at the same time carefully picked out. The stones, the roots, and the remaining soil, are thus obtained separately; and the determinations of dry matter, of nitrogen, and sometimes of carbon, and of other constituents, are made in the separated soil after being finely powdered. The loss of water at each stage of preparation, and on drying the samples as analysed, is also carefully determined.

In January 1879 six samples from so many different places in the field were taken, and in September 1888 five samples. Table IV. (below) shows, in the upper division for each of the

TABLE IV.—SOIL SAMPLES COLLECTED JANUARY 1, 1879, AND SEPTEMBER 26, 1888.

Quantities per acre.

Samples	Original soil as sampled	Stones, &c.	Roots, &c.	Water	Fine soil (dry)
	Samples collected January 1, 1879.				
	lbs.	lbs.	lbs.	lbs.	lbs.
1	3,642,024	800,061	10,400	769,040	2,062,523
2	3,680,139	916,012	12,741	761,757	1,989,629
3	3,647,469	894,613	8,875	762,057	1,981,924
4	3,708,726	823,638	11,816	765,204	2,108,068
5	3,771,343	1,028,125	9,529	782,051	1,951,638
6	3,735,951	983,258	16,008	778,961	1,957,724
Mean	3,697,609	907,618	11,561	769,846	2,008,584
	Samples collected September 26, 1888.				
1	3,360,926	1,002,969	10,346	549,603	1,798,008
2	3,422,183	1,035,367	11,707	550,863	1,824,246
3	3,170,351[1]	878,279	7,623	423,327	1,861,122
4	3,449,408	752,771	9,901	627,722	2,059,114
5	3,431,711	852,551	12,523	564,235	2,002,402
Mean	3,366,915	904,387	10,400	543,150	1,908,978

[1] Probably too little, as the soil appeared to rise in the sampling iron, owing, as was afterwards found, to a large stone directly under the edge of the frame; probably part of this stone should have been included in the weight of sample.

six 1879 samples, and in the lower division for each of the five 1888 samples, the calculated amounts per acre of the total soil as sampled, of the stones, the roots, the water, and, finally, of the fine soil free of water.

It will be seen that, according to the calculations, the average weight of total soil per acre, to the depth of 9 inches, was about 330,000 lbs., or about one-eleventh less in September 1888 than in January 1879. An examination of the amounts of water shows that about two-thirds of the difference was due to the less amount of moisture in the soil of the 1888 samples, taken in September, and after the removal of a second crop of hay, than in those taken in January 1879, six months after the removal of the crop. The remaining difference, amounting to rather more than 100,000 lbs., is made up by rather over 3,000 lbs. less stones, rather over 1,000 lbs. less roots, and very nearly 100,000 lbs. less dry soil; corresponding, in fact, to about 5 per cent., or one-twentieth less dry soil in 1888 than in 1879.

It may be observed that the difference in the amount of water per acre, to the depth of 9 inches, at the two periods, corresponds to a difference of almost exactly 1 inch less rain retained in the first 9 inches of depth in September 1888 than in January 1879; and the less amount of soil removed at the later date is probably, in great part, due to less consolidation of the drier soil. The average amounts of water represent about 20·8 per cent. of the soil as sampled in 1879, but only 16·1 per cent. in 1888.

It is seen that, on the average, the stones amounted in 1879 to nearly one-fourth, but in 1888 to more than one-fourth of the total soil as sampled; and, in each case, the stones amounted to not far short of half as much as the fine dry soil, which is a larger proportion than has been found in any, and a much larger proportion than in most, of the surface-soils, of the Rothamsted experimental arable fields. The amounts varied, however, considerably according to the different samples, and more in those taken in 1888 than in those of 1879.

The amount of roots also varied considerably in the different samples, but more in 1879 than in 1888; the quantity corresponding in one case in 1879 to 8,875 lbs. per acre, and in another to 16,008 lbs.; whilst in 1888 the greatest difference was from 7,623 lbs. in one case, to 12,523 lbs. in another. On the average there was about one-eleventh less roots in 1888 than in 1879; whilst we should expect an increase with the progress in the formation of the meadow. Part of the difference is accounted for by the less amount of total soil taken to the depth of 9 inches in the drier state of the soil in 1888; and it

is probable that some of the deficiency may be due to the roots being more exhausted after the removal of a second crop in September, than in January after no removal by mowing since the preceding summer. The amount of nitrogen in the roots at the two periods will be considered further on.

The amount of water varied comparatively little in the six samples taken in January 1879, but more, with the less actual quantities, in the five samples of 1888.

Lastly, as to the fine soil free from water, the variation in the amount in the different samples has obviously some relation to the amount of stones; but, taking the average, the 1879 samples represent 2,008,584 lbs., and the 1888 samples only 1,908,978 lbs., or, as has been said, about one-twentieth less. The significance of this difference will be seen as we proceed.

Two or more determinations of nitrogen were made in each separate sample, in each of the two years, and also in a mixture of the six samples of 1879, and of the five of 1888. The following Table (V.) gives the mean percentage of nitrogen in each separate sample, and in the mixture for each year. It also gives the amounts of nitrogen per acre, in lbs., to the depth of 9 inches, calculated from these percentages, and the actual weights of soil in each case, as given in the preceding Table, and, for convenience, repeated in the first two columns of the Table below.

TABLE V.—NITROGEN PER CENT., AND PER ACRE, IN THE SURFACE-SOILS TO THE DEPTH OF 9 INCHES, IN JANUARY 1879, AND SEPTEMBER 1888.

Samples	Fine soil (dry) per acre		Nitrogen			
			Per cent.		Per acre	
	1879	1888	1879	1888	1879	1888
	lbs.	lbs.	per cent.	per cent.	lbs.	lbs.
No. 1	2,062,523	1,798,008	0·1975	0·2477	4,073	4,454
„ 2	1,989,629	1,824,246	0·2013	0·2388	4,005	4,356
„ 3	1,981,924	1,861,122	0·2112	0·2614	4,186	4,865
„ 4	2,108,068	2,059,114	0·1942	0·2380	4,094	4,901
„ 5	1,951,638	2,002,402	0·2048	0·2255	3,997	4,515
„ 6	1,957,724	—	0·2051	—	4,015	—
Mean . . .	2,008,584	1,908,978	0·2024	0·2423	4,062	4,618
Mixture . . .	—	—	0·2057	0·2405	4,132	4,591
Mean of mean and mixture	—	—	0·2041	0·2414	4,097	4,604

Referring first to the 1879 results, the percentage of nitrogen is not widely different in the different samples. The highest is 0·2112 per cent. in sample 3, and the lowest 0·1942 in sample 4.

But with the higher percentage the weight of fine dry soil per acre was only 1,981,924 lbs., whilst with the lower it was 2,108,068 lbs.; so that there is only a difference of from 4,186 to 4,094, or 92 lbs., in the calculated quantity of nitrogen per acre in the two cases. There can be little doubt that the lower percentage in the sample of greater actual weight of fine dry soil was due partly, at any rate, to the inclusion of a greater quantity of subsoil which would contain a lower percentage of nitrogen. The percentage of nitrogen according to the mean of the determinations on the six individual samples is 0·2024, and according to the determinations on a mixture of the six samples it is 0·2057, showing a difference, therefore, of only 0·0033 per cent.

The calculated quantities per acre are, according to the mean of the determinations on the six individual samples, 4,062 lbs. per acre, and according to the determinations on the mixture 4,132 lbs., or a difference of 70 lbs. on a total quantity of about 4,100 lbs.

Turning to the 1888 results, the difference in the percentage of nitrogen in the different samples is rather greater than in those of 1879; and there is again some, but not an uniform, indication of higher percentage with lower weight of soil, and lower percentage with higher weight—that is, with probably more subsoil included. The mean percentage on the individual samples is 0·2423, and on the mixture 0·2405, or a difference of only 0·0018 per cent.

There is also a greater difference in 1888 than in 1879 in the calculated amounts of nitrogen per acre from the different samples; but there is very little difference between the average result on the five individual samples, and that on the mixture—it being 4,618 lbs. according to the analyses and calculations on the separate samples, and 4,591 lbs. according to the results on the mixed sample—that is, there is a difference of only 27 lbs. per acre, in a total of about 4,600 lbs.

Taking the results as they stand—though, as we shall see further on, they will require some modification before being finally adopted—the average percentage of nitrogen in the 1879 samples was 0·2041, but in the 1888 samples 0·2414, or about one-fifth higher, after nearly ten years. Or, taking the calculated amounts of nitrogen per acre to the depth of 9 inches, they were 4,097 lbs. in 1879, and 4,604 lbs. in 1888; showing an increase, therefore, of 507 lbs. in the nearly ten years, or about 50 lbs. per acre per annum, during so many years of the further progress in the formation of the meadow.

Before referring further to these results, we must endeavour to arrive at some estimate of the amount of nitrogen in the surface-soil when it was first taken in hand as arable land. As

already said, no samples were taken at the commencement; but having taken so many samples of our arable soils to the depth of 9 inches, and determined the nitrogen in them, we believe we may safely assume that, at the commencement, the arable surface-soil would, to that depth, contain about 0·14 per cent. of nitrogen.

But the average weight of fine dry soil, to the depth of 9 inches, would, when arable, weigh about 2,400,000 lbs. per acre, instead of about 2,000,000 lbs. as in the case of the land after it had been so many years under grass. We have, therefore, to estimate what would probably be the percentage of nitrogen in the upper 2,000,000 lbs. of the surface arable soil. That is to say, we have, in the first place, to deduct 400,000 lbs., or one-sixth of the original weight, and to deduct the amount of nitrogen it would contain from the total, and calculate the percentage in the remaining upper 2,000,000 lbs. Taking the original 2,400,000 lbs. at 0·14 per cent. of nitrogen, the total amount to the depth of 9 inches would be 3,360 lbs. of nitrogen per acre. Assuming the lower inch and a half, or one-sixth = 400,000 lbs., which would be below the reach of the plough, to contain only 0·08 per cent. of nitrogen, the total amount of nitrogen in it would be 320 lbs. per acre; and deducting this from the total 3,360 lbs., there remain 3,040 lbs. in the upper 2,000,000 lbs. of the fine dry soil of the arable land at the commencement, and this would correspond to a percentage of 0·152 in the 2,000,000 lbs. of surface-soil.[1]

We have thus an estimate of the percentage, and of the total amount, of nitrogen in 2,000,000 lbs. of fine dry arable surface-soil in 1856, when the land was taken in hand; we have actual determinations in the surface-soil, weighing rather over 2,000,000 lbs. in 1879; and we have actual determinations in 1888, when, however, the fine dry soil to the depth of 9 inches amounted to little more than 1,900,000 lbs. Before, therefore, we can make any accurate comparison of the amounts of nitrogen at the different dates, we must correct the results of the actual determinations, so as to show the amount in 2,000,000 lbs. For example, we assume that the about one-twentieth, or nearly 100,000 lbs. deficiency of weight per acre in 1888, being subsoil, but influenced more or less by the perennial vegetation, would contain about 0·09 per cent. of nitrogen, and the calculation is as follows:—91,000 lbs. of subsoil, at 0·09 per cent. nitrogen = 82 lbs. of nitrogen per acre, which added to 4,604 lbs., the amount by actual determination in 1,908,978 lbs., gives a total of 4,686 lbs. nitrogen in

[1] It is perhaps more probable that these estimates of the percentage, and of the actual amount, of nitrogen in the surface soil in 1856, are too high than too low.

2,000,000 lbs. of soil, corresponding to 0·234 per cent. in the 2,000,000 lbs., instead of 0·2414 per cent. on 1,908,978 lbs. as given in Table V. of the actual experimental results.

It will be seen, therefore, that in endeavouring to estimate the loss or gain in the nitrogen of a surface-soil, under any particular mode of treatment, we have to face a very complicated problem, and one which is not generally recognised. It is, however, essential to meet the difficulty, if we would arrive at anything like trustworthy conclusions.

Adopting the plan of calculation above described, we have—reckoning in each case 2,000,000 lbs. of dry surface-soil per acre—estimates of the percentage of nitrogen, and of the actual amounts of it, in lbs. per acre, in 1856, when the land was arable; estimates for 1866, the time from which our records of manure and produce commence; direct determinations in 1879, when the first samples were taken; and direct determinations also for 1888, when the last samples were taken and analysed. The following Table shows the results so obtained, and also the estimated gain of nitrogen, per acre per annum, over individual periods, and the total period:—

TABLE VI.—NITROGEN PER CENT. IN SURFACE-SOIL (DRY); ALSO ACTUAL QUANTITIES, AND GAIN, IN LBS. PER ACRE, AT DIFFERENT PERIODS.

Dates	Number of years	Nitrogen			
		Per cent. in surface-soil (dry)	Per acre total	Gain	
				Per acre total	Per acre per annum
		per cent.	lbs.	lbs.	lbs.
1856	—	0·1520	3,040	—	—
1866	10	0·1749	3,497	457	45·7
1879	13	0·2046	4,091	594	
1888	10	0·2345	4,690	599	59·9
—	33	—	—	1,650	50·0

Taking into consideration both the treatment of the land as to manuring, and the amounts of crop grown, there can be no doubt that there would be greater accumulation of nitrogen within the surface-soil over the later than over the earlier years; and it is seen that, according to the calculations, there was an estimated average gain of 45·7 lbs. per acre per annum over the period from 1856 to 1879, but of 59·9 lbs. per acre per annum over the last ten years. It is probable that the average gain was rather less per acre per annum over the first ten years, and

rather more over the next thirteen, than over the total period of twenty-three years, from 1856 to 1879. The estimate for the concluding period from 1879 to 1888 (reckoned at ten years from the removal of the crop of 1878) is, however, founded on direct experimental data, and is probably very near the truth. The average annual gain over the 33 years, 1856 to 1888, is seen to be 50·0 lbs. per acre; and the average over the 23 years from 1866 to 1888, to which our records of manure and produce relate, is 51·9 lbs.

The gain so indicated is obviously independent of the visible and separated underground vegetable matter, roots, &c. The following Table (VII.) shows the amounts of roots per acre in the surface-soil, the percentage of nitrogen in them, and the amounts of nitrogen per acre, according to the results on each sample in 1879 and in 1888 respectively:—

TABLE VII.—SEPARATED ROOTS PER ACRE, AND NITROGEN IN THEM, PER CENT. AND PER ACRE.

Sample	Roots per acre		Nitrogen in roots (air-dried)			
			Per cent.		Per acre	
	1879	1888	1879	1888	1879	1888
	lbs.	lbs.	per cent.	per cent.	lbs.	lbs.
1	10,400	10,346	0·740	0·771	77·0	79·8
2	12,741	11,707	0·696	0·800	88·7	93 6
3	8,875	7,623	0·804	0·805	71·4	61·4
	11,816	9,801	0·795	0·644	93·9	63·1
5	9,529	12,523	0·802	0·731	76·4	91·6
6	16,008	—	0·766	—	122·6	—
Mean	11,561	10,400	0·767	0 750	88·3	77·9

Attention has already been called to the fact that, although the soil had undoubtedly increased in fertility during the last 10 years, as proved both by the increased amounts of crop, and by the increased amount of nitrogen in the surface-soil, yet there was even a somewhat less amount of roots separated from the samples of soil in 1888 than in 1879. It was supposed probable that part of the result might be due to the roots being more exhausted in September 1888, after the removal of two large crops, than in January 1879, when no hay-crop had been removed since the preceding summer. It may be, however, that the separation of fine vegetable matter was more complete in the case of the 1879 than in that of the 1888 samples; and, so far as this was so, a small portion of the increased amount of nitrogen found in the fine dry soil in 1888 would be due to

such fine vegetable débris. Against such a supposition is the fact that determinations of carbon in the mixture of the six 1879 and of the five 1888 soil samples show scarcely any increased relation of carbon to nitrogen at the later date, the amounts being 11·73 carbon to 1 of nitrogen in 1879, and only 11·77 in 1888. Compared with these amounts, as already stated, there are from 13 to 14 parts of carbon to 1 of nitrogen in the surface-soil of the old grass-land at Rothamsted.

At any rate, the figures in Table VII. show that the average amounts of nitrogen per acre due to separated roots were rather less at the later date, being 88·3 lbs. in 1879, and only 77·9 lbs. in 1888. These amounts are much less than were attributable to separated roots in the case of the old grass-land.

Upon the whole, therefore, the evidence clearly indicates that there is much less accumulation of vegetable débris in the surface-soil of the new, than in that of the old grass-land. As to the actual amounts of nitrogen due to vegetable accumulation in the surface-soil, if the whole amount were distributed over the 33 years, it would represent less than 3 lbs. per acre per annum. But, obviously, a larger part of the earlier than of the later accumulations will have been decomposed, and will have contributed to the increase of nitrogen and carbon found in the fine soil. Hence, more than the above calculated average amount, both of vegetable débris and of nitrogen in it, will be due to the later years. Still, the amounts of nitrogen due to such accumulations of visible and separable vegetable matter will not add many lbs. per acre per annum to the amounts remaining and found in the fine soil itself.

From the whole of the results there can be no doubt that there has been a considerable accumulation of nitrogen in the surface-soil during the formation of the meadow—amounting, in fact, to an average of nearly 52 lbs. per acre per annum over the last 23 years. The question arises—whence has this nitrogen been derived?

In Table III. it was shown that, on the assumption of the lower percentage of nitrogen (0·64) in the dung applied, there were 7·9 lbs. more nitrogen annually supplied in manure than were removed in the crops, over the 23 years 1866 to 1888; but that, on the assumption of the higher percentage of nitrogen in the dung (0·80), there were about 20 lbs. (20·1) more annually supplied than were removed in the crops; or, even if we were to suppose that the dung contained 1·0 per cent. of nitrogen, the excess in manure over that in the crops would only amount to 35·4 lbs. per acre per annum.

It is obvious that, even supposing there were no loss of the

supplied nitrogen, either by decomposition within the soil and evolution of free nitrogen, or by the drainage of nitric acid, the estimated excess in the manure over that in the crops removed would not account for the indicated gain of nitrogen by the surface-soil, and in the roots. We may also reckon that the meadow received nitrogen at the rate of about 5 lbs. per acre per annum, by cake or corn given to the animals feeding off the second crops. There will also be from 5 to 10 lbs. per acre per annum, due to combined nitrogen coming down in rain and the minor aqueous deposits from the atmosphere.

Making full allowance for the various sources that have been enumerated, there would still appear to be a greater or less balance of the gain not so accounted for. If so, it must have its source, either in the subsoil, or the atmosphere, or both.

There is much experimental evidence pointing to the conclusion that, at any rate some deep-rooted leguminous plants derive a considerable quantity of nitrogen from the subsoil; and there seems no reason to doubt that the deep-rooting plants of the mixed herbage of grass-land, whether leguminous or otherwise, may also avail themselves of subsoil nitrogen; and, if so, it is to be supposed that they, like clover for example, will leave nitrogenous crop-residue in the surface-soil, the nitrogen of which has been derived from the subsoil.

It is, indeed, very probable that, at any rate the greater part, if not the whole, of the nitrogen gained by the surface-soil, and not accounted for by the excess supplied in manure over that removed in crops, or by combined nitrogen from the atmosphere, is due to nitrogen of the subsoil. But if the whole is not to be so accounted for, the question remains—whether some may not be derived in some way from the free nitrogen of the atmosphere?

On this point we think it may safely be concluded, from the results of the experiments of Boussingault, and of those made at Rothamsted, many years ago, that our agricultural plants do not themselves directly assimilate the free nitrogen of the air by their leaves. But in recent years the question has assumed quite a new aspect. It now is, whether the free nitrogen of the atmosphere is brought into combination within the soil, under the influence of micro-organisms, or other low forms, and so serving indirectly as a source of nitrogen to plants of a higher order?

Thus, Hellriegel and Wilfarth have found, in experiments with various leguminous plants, that if a soil free of nitrogen have added to it a small quantity of soil-extract containing the organisms, the plants will fix much more nitrogen than was

otherwise available to them in the combined form. It further seemed probable, that the growth and crop-residue of certain plants favoured the development and action of special organisms. It is admittedly not yet understood, either in what way the lower organisms affect the combination, or in what way the higher plants avail themselves of the nitrogen thus brought into combination.

Thinking that such results, if confirmed, were of very great significance, and the conclusions to be drawn from them were of fundamental importance, we decided to institute experiments at Rothamsted on somewhat similar lines. An initiative series has already been undertaken. At present, however, the analytical results are not complete; but, so far as they go, they seem to indicate the probability that there has been some gain of nitrogen beyond that supplied in the combined form, in the soil and in the seed sown. It is remarkable, however, that in the experiments of Hellriegel and Wilfarth they have not succeeded in enhancing the assimilation of nitrogen by red clover by such means. The plants with which their most striking results have been obtained are peas and lupins; and it is with peas that the indications have been obtained at Rothamsted. Should it be finally established, that such an action does take place in the case of certain plants, though not in that of others, it is obvious that part at any rate of the gain of nitrogen by the soil supporting the mixed herbage of grass-land, may be due to the free nitrogen of the air brought into combination under the influence of the action supposed.

The Botany of the Meadow.

Botanical separations in samples of the herbage have not been undertaken; but careful examinations of its character have been made from time to time by Mr. J. J. Willis, who conducts the botanical work of the Rothamsted experiments; and Table VIII. (page 24) gives the results of his estimates, made in November 1868, and in eleven recent years a short time before cutting, of the five most prominent grasses, the four most prominent leguminous plants, and the four most prominent miscellaneous or weedy species. It will be seen that, with the exception of 1877 and 1884, the recent seasons were 1876–88.

Before referring to the results relating to recent years, attention should be directed to the notes taken at the earlier period, namely in 1868. It was then stated, that *Dactylis glomerata* (cock's-foot) was plentiful, *Poa pratensis* (smooth-stalked meadow-grass) abundant and luxuriant, *Lolium perenne* (perennial rye-

Table VIII.—Order of Predominance of the most prominent Species in the Mixed Herbage.

	Order of Predominance				
	First	Second	Third	Fourth	Fifth
			Gramineæ		
1868	Dactylis glomerata	Poa pratensis	Lolium perenne	Festuca ovina	Bromus mollis
1876	Holcus lanatus	Festuca ovina	Poa pratensis	Anthoxanthum odoratum	Avena flavescens
1878	Bromus mollis	Lolium perenne	Alopecurus pratensis	Holcus lanatus	Anthoxanthum odoratum
1879	Holcus lanatus	Avena flavescens	Anthoxanthum odoratum	Poa trivialis	Festuca ovina
1880	Alopecurus pratensis	Anthoxanthum odoratum	Poa pratensis	Holcus lanatus	Lolium perenne
1881	Poa trivialis	Avena flavescens	Festuca ovina	Holcus lanatus	Anthoxanthum odoratum
1882	Bromus mollis	Festuca ovina	Lolium perenne	Holcus lanatus	Anthoxanthum odoratum
1883	Holcus lanatus	Alopecurus pratensis	Festuca ovina	Poa trivialis	Lolium perenne
1885	Avena flavescens	Holcus lanatus	Bromus mollis	Alopecurus pratensis	Festuca ovina
1886	Alopecurus pratensis	Holcus lanatus	Festuca ovina	Poa pratensis	Avena flavescens
1887	Poa trivialis	Avena flavescens	Festuca ovina	Holcus lanatus	Lolium perenne
1888	Alopecurus pratensis	Avena flavescens	Poa pratensis	Poa trivialis	Holcus lanatus
			Leguminosæ		
1868	Trifolium repens	Lotus corniculatus	Trifolium pratense	Lathyrus pratensis	
1876	Trifolium minus	Trifolium pratense	Lotus corniculatus	Lathyrus pratensis	
1878	Trifolium pratense	Trifolium repens	Lotus corniculatus	Medicago lupulina	
1879	Trifolium repens	Trifolium minus	Trifolium pratense	Lathyrus pratensis	
1880	Trifolium minus	Trifolium pratense	Trifolium repens		
1881	Trifolium minus	Trifolium pratense	Trifolium repens		
1882	Trifolium minus	Trifolium pratense	Trifolium repens		
1883	Trifolium minus	Trifolium pratense	Trifolium repens		
1885	Trifolium pratense	Trifolium repens	Trifolium minus	Lotus corniculatus	
1886	Trifolium repens	Trifolium minus	Trifolium pratense	Lathyrus pratensis	
1887	Trifolium pratense	Trifolium minus	Lathyrus pratensis		
1888	Trifolium pratense	Trifolium repens	Trifolium minus		
			Species of Other Orders.		
1868	Rumex acetosa	Plantago lanceolata	Ranunculus acris & bulbosus	Hypochœris radicata	
1876	Ranunculus bulbosus	Hypochœris radicata	Bellis perennis	Chrysanthemum leucanthemum	
1878	Ranunculus bulbosus	Plantago lanceolata	Bellis perennis	Taraxacum officinale	
1879	Ranunculus bulbosus & acris	Rumex acetosa	Plantago lanceolata	Cerastium triviale	
1880	Conopodium denudatum	Luzula campestris	Rumex acetosa	Ranunculus acris	
1881	Rumex acetosa	Ranunculus bulbosus	Cerastium triviale	Achillea millefolium	
1882	Rumex acetosa	Ranunculus bulbosus	Cerastium triviale	Achillea millefolium	
1883	Rumex acetosa	Chrysanthemum leucanthemum	Bellis perennis	Achillea millefolium	
1885	Ranunculus bulbosus	Rumex acetosa	Ranunculus acris	Cerastium triviale	
1886	Rumex acetosa	Ranunculus bulbosus	Cerastium triviale	Anthriscus sylvestris	
1887	Achillea millefolium	Rumex acetosa	Anthriscus sylvestris	Ranunculus acris & bulbosus	
1888	Rumex acetosa	Cerastium triviale	Achillea millefolium	Ranunculus acris & bulbosus	

grass) was third in prominence, *Festuca ovina* (sheep's-fescue) plentiful, and *Holcus lanatus* (woolly soft grass), *Agrostis vulgaris* (common bent grass), and *Bromus mollis* (soft brome-grass), were freely distributed. Leguminous species were found to be very abundant; *Trifolium repens* (white clover) and *Lotus corniculatus* (bird's-foot trefoil) being exceedingly prominent, especially the latter. *Trifolium pratense* (red clover) was less abundant, and but little of *Lathyrus pratensis* (meadow vetchling) was observed. Miscellaneous species were in fair amount; *Rumex acetosa* (sorrel dock), *Taraxacum officinale* (dandelion), *Plantago lanceolata* (ribwort plantain), and *Ranunculus repens* and *bulbosus* (buttercups), were the most characteristic. In all, 13 grasses, 4 leguminosæ, and 29 miscellaneous species, making a total of 46, were observed.

In 1876, that is, eight years later, *Dactylis* was not among the five most prominent grasses nor did it reach that degree of prominence in any one of the last ten years. *Lolium perenne*, again, which was rather prominent in the early years, and was third in prominence in 1868, was not among the first five in 1876, was, however, second in 1878, was not placed in 1879, was only fifth in 1880, was not placed in 1881, was third in 1882, fifth in 1883, not placed in 1885 or 1886, was only fifth in 1887, and was not placed in 1888. Both cock's-foot and ryegrass have, therefore, much diminished in prominence under constant mowing; whilst among the better grasses, *Alopecurus pratensis*, *Avena flavescens*, and the two *Poas*, attain and maintain a prominent place, but the less favourably reputed *Holcus lanatus* and *Festuca ovina* are more prominent still. Of leguminous plants, *Trifolium minus*, *T. pratense*, and *T. repens*, are the most prominent, whilst *Lotus* and *Lathyrus* are comparatively scarce. In fact, notwithstanding the mowing, the frequent application of dung, and the feeding of the after-grass, generally with a small quantity of purchased food, have tended to maintain a fair proportion of leguminous herbage; whilst, the more there was used of artificial nitrogenous manure, and the more luxuriant and stemmy the grasses were accordingly, the less was the proportion of leguminous herbage; and it was this fact that led to a reduction in the amount of nitrate of soda applied in later years. Upon the whole, weedy herbage is not prominent; but of such, *Ranunculus*, *Rumex*, and *Achillea* are the most so.

It appears, therefore, that neither *Dactylis* nor *Lolium* maintains any prominence when the herbage is annually mown. This result is entirely accordant with that obtained in the Rothamsted permanent grass experiments. In the early years *Dactylis* was the most prominent grass on the highly manured

plots, but it is now comparatively scarce, being mainly replaced by *Alopecurus* and *Avena elatior*. *Lolium*, too, has almost disappeared in recent years.

Upon the whole, it may be concluded from these results of annual mowing for nearly thirty years, that fair quality of herbage, as well as full quantity, may be maintained, provided judgment be exercised in the manuring. Indeed, it is seen that the quantity of crop is gradually increasing, indicating an improving condition of the land under the treatment followed.

Summary and General Conclusions.

1. By the judicious employment of manures, both natural and artificial, arable land has been converted into permanent grass, not only without loss, but with some profit to the tenant.

2. The important constituents, nitrogen and phosphoric acid, were supplied in the manures in larger quantities than they were removed in the crops; but potash in only about the same quantity as it was removed.

3. The application of dung, not only compensates for much of the exhaustion from the removal of hay, but it has a beneficial influence on the botanical character of the herbage.

4. Although the grass has been mown every year for nearly thirty years, there has been a considerable accumulation of fertility within the soil.

5. Analysis has shown that there has been an increase of nitrogen in the surface-soil, beyond that which could be explained by excess supplied in manure over that removed in crops, and by the combined nitrogen coming down in rain, and the minor deposits, from the atmosphere. Part, if not the whole, of this increase is probably derived from the subsoil by deep-rooted plants, which afterwards leave a nitrogenous residue within the surface-soil. Or, possibly, some of it may have its source in the free nitrogen of the atmosphere, brought into combination within the soil, under the influence of micro-organisms, or other low forms.

6. In laying down arable land to permanent grass, especially if hay is to be removed, it is essential to supply, not only nitrogenous, but an abundance of mineral manures, and especially of potash, a large quantity of which is removed in the crops, and must be returned. When the grass is not mown, but fed, the exhaustion is much less, but it is greater when consumed for the production of milk, than when for that of store or fattening increase.

RESULTS OF EXPERIMENTS AT ROTHAMSTED,

ON THE

GROWTH OF

LEGUMINOUS CROPS,

FOR MANY YEARS IN SUCCESSION
ON THE SAME LAND;

BEING

(WITH ADDITIONS)

A LECTURE DELIVERED NOVEMBER 1, 1889,

AT THE

ROYAL AGRICULTURAL COLLEGE,

CIRENCESTER,

BY

J. H. GILBERT, M.A., LL.D., F.R.S.,

SIBTHORPIAN PROFESSOR OF RURAL ECONOMY
IN THE UNIVERSITY OF OXFORD,

AND

HONORARY PROFESSOR OF THE COLLEGE.

FROM THE "AGRICULTURAL STUDENTS' GAZETTE."
NEW SERIES.—VOL. IV., PARTS V. AND VI.

TABLE OF CONTENTS.

PAGE

INTRODUCTION 1

YIELD OF NITROGEN PER ACRE PER ANNUM IN DIFFERENT CROPS, WITHOUT NITROGENOUS MANURE (Table I., p. 3, and Table II., p. 5) 2

YIELD OF NITROGEN IN THE CROPS OF A MANURED ROTATION (Table III., p. 7) 6

PERCENTAGE OF NITROGEN IN THE DRY SUBSTANCE OF VARIOUS CROPS (Table IV., p. 8) 8

EFFECTS OF NITROGENOUS MANURES IN INCREASING THE PRODUCE OF VARIOUS CROPS (Table V., p. 10) 9

EFFECTS OF NITROGENOUS MANURES ON LEGUMINOUS CROPS (Table VI., p. 14, Table VII., p. 17, and Table VIII., p. 19) 13

GROWTH OF RED CLOVER, YEAR AFTER YEAR, ON RICH GARDEN SOIL (Table IX., p. 21, and Table X., p. 23) 20

PRODUCE OF NITROGEN IN THE MIXED HERBAGE OF GRASS LAND (Table XI., p. 25, and Table XII., p. 26) 25

RED CLOVER GROWN AFTER BEANS (Table XIII., p. 28, and Table XIV., p. 29) 27

VARIOUS LEGUMINOUS PLANTS GROWN AFTER RED CLOVER (Table XV., p. 32, Table XVI., p. 33, and Table XVII., p. 36) 30

EXPERIMENTS ON THE NITRIFICATION OF SOILS AND SUB-SOILS 38

CAN ROOTS, BY VIRTUE OF THEIR ACID SAP, ATTACK, AND RENDER AVAILABLE, THE OTHERWISE INSOLUBLE NITROGEN OF THE SUB-SOIL? 41

ACTION OF DILUTE ORGANIC ACID SOLUTIONS ON THE NITROGEN OF SOILS AND SUB-SOILS 41

EVIDENCE AS TO THE FIXATION OF FREE NITROGEN 44

SUMMARY AND GENERAL CONSIDERATIONS ON THE SOURCES OF THE NITROGEN OF OUR CROPS 52

RESULTS OF EXPERIMENTS AT ROTHAMSTED, ON THE GROWTH OF LEGUMINOUS CROPS, FOR MANY YEARS IN SUCCESSION ON THE SAME LAND.

INTRODUCTION.

The subject of my lecture to-day is—the conditions, and the results of growth, of Leguminous Crops; and, as on former occasions, I propose to draw my illustrations largely from the results of field experiments, and other investigations, conducted at Rothamsted.

In former lectures I have, in a similar way, considered the conditions and the results of growth—of Wheat, and of Barley, as representatives of the great gramineous family; of some varieties of Turnips, representing the *Cruciferæ*; of some varieties of Beet, representing the *Chenopodiaceæ*; and of Potatoes, of the *Solaneæ*.

It was found that, within certain limits, the requirements, and the results of growth, of different members of one and the same family, showed certain characteristics in common; whilst those of different families showed more or less of distinctive character. Nevertheless, there are some important points of similarity, as well as of contrast, between the requirements of the agricultural representatives of the *Gramineæ*, the *Cruciferæ*, the *Chenopodiaceæ*, and the *Solaneæ*.

It will be seen, however, that the agricultural representatives of the *Leguminosæ*, all of which are included in the sub-order *Papilionaceæ*, and some of which are of much importance in our agriculture, show very marked differences, as compared with those of any of the other families I have enumerated.

It so happens that, both the scientific interest, and the practical value, of these crops, whether as elements in rotation, or as grown in the mixed herbage of grass-land, depend very largely on the amount of nitrogen which they contain, and on the sources of their nitrogen; and especially on the great differences in these respects, between them, and the representatives of the other families with which they are grown, either in alternation in our rotations, or in association in our meadows and pastures.

So much is this the case, that it is essential to a proper understanding and appreciation, of the characteristics of growth of these crops, and for the illustration of their value and importance as depending on those characteristics, to compare and to contrast the conditions and results of their growth, with those of the crops of other families.

I will first call attention to the difference in the amounts of nitrogen assimilated over a given area by different crops, when each is grown

for many years in succession on the same land, without any nitrogenous manure; or when grown in alternation one with another, also without nitrogenous manure; that is to say, under conditions in which the soil is to a great extent exhausted of accumulations of nitrogen due to recent supplies by manure, and when, therefore, the plants have to rely largely on what may be called the natural resources of the soil, and on those of the atmosphere.

I shall next show the effects of artificial supplies of nitrogen, on the growth of the different descriptions of plant, on the amount of nitrogen they assimilate, and on the amount and character of their products.

Lastly, I shall adduce evidence of quite other kinds, as to the sources of the nitrogen, more especially of the *Leguminosæ*; a question which has been the subject of experimental enquiry, and at times of active controversy, for about half a century; which has in recent years assumed a somewhat new aspect; but which cannot even yet be said to be conclusively settled.

YIELD OF NITROGEN PER ACRE PER ANNUM IN DIFFERENT CROPS, WITHOUT NITROGENOUS MANURE.

Table I. (p. 3), shows the yield of nitrogen per acre per annum, with mineral, but without any nitrogenous manure—in Wheat and in Barley as *Gramineous* crops, in Turnips as representatives of the *Cruciferæ*, in Sugar-Beet and Mangel-Wurzel of the *Chenopodiaceæ*, and in Beans and Clover as *Leguminous* crops, when each is grown for many years in succession on the same land. It also shows, the amounts of nitrogen yielded per acre, when Turnips, Barley, a Leguminous crop, and Wheat, are grown in an actual course of rotation, also with mineral, but without nitrogenous manure.

Incidentally it is to be noticed that, in the case of each of the crops—Wheat, Barley, and Beans—thus grown year after year on the same land for many years in succession without nitrogenous manure, there was a reduction in the yield of nitrogen per acre per annum, over the second period compared with the first; that is, as the accumulations within the soil became reduced.

Disregarding this tendency to reduced yield, it is seen that, over the same period of 24 years, with full mineral but without nitrogenous manure, the wheat yielded an average of 22·1 lbs., and the barley 22·4 lbs. of nitrogen per acre per annum; the two allied crops, therefore, yielding almost identical amounts, in their above-ground produce, without nitrogenous manure, on soil very poor in available nitrogen, so far as accumulations due to recent applications of nitrogenous manure are concerned.

Turning now to the yield of nitrogen in the root-crops,—Turnips, Sugar-Beet, and Mangel-Wurzel—it may be mentioned that, prior to the period referred to in the Table, Turnips had been grown for a number of years, and had yielded 42 lbs. of nitrogen per acre per

annum, due to the accumulations from comparatively recent nitrogenous manuring. But, it is seen that, after these accumulations had been reduced, Swedish Turnips gave over 15 years, an average of only 18·5 lbs., Sugar-Beet over the next 5 years, an average of only 14·7 lbs., and Mangel-Wurzel over the succeeding 10 years, an average of only 14·0 lbs. of nitrogen, per acre per annum. Or, reckoned over the whole period of 30 years, after the recent accumulations had been worked out, the root-crops gave an average of only 16·4 lbs. of nitrogen per acre per annum.

TABLE I.

Nitrogen per acre per annum, in various Crops grown at Rothamsted, with Mineral, but without Nitrogenous Manure.

		Duration of Experiment.	Average Nitrogen per acre per annum.
			lbs.
Wheat		12 years, 1852-1863 ..	27·0
		12 years, 1864-1875 ..	17·2
		24 years, 1852-1875 ..	22·1
Barley		12 years, 1852-1863 ..	26·0
		12 years, 1864-1875 ..	18·8
		24 years, 1852-1875 ..	22·4
Root-crops	Swedish Turnips	*15 years, 1856-1870 ..	18·5
	Sugar Beet	5 years, 1871-1875 ..	14·7
	Mangels	10 years, 1876-1885 ..	14·0
	Total	30 years, 1856-1885 ..	16·4
Beans		12 years, 1847-1858 ..	61·5
		†12 years, 1859-1870 ..	29·5
		24 years, 1847-1870 ..	45·5
Clover		‡22 years, 1849-1870 ..	39·8
Rotation (8 courses)	1. Swedish Turnips	32 years, 1852-1883	33·3
	2. Barley		23·5
	3. Clover (2 courses) ..		124·5
	Beans (6 courses)		40·5 §
	Average Clover and Beans		61·5
	4. Wheat		35·9
	Average all Crops		38·6

* 13 years crop, 2 years failed.
† 9 years beans, 1 year wheat, 2 years fallow.
‡ 6 years clover, 1 year wheat, 3 years barley, 12 years fallow.
§ Superphosphate only.

It is remarkable, how very similar is the amount of nitrogen annually accumulated in Gramineous, Cruciferous, and Chenopodiaceous crops, after the soil had been exhausted of the more recent and more

readily available nitrogenous accumulations. Thus, over the second half of the period, the Wheat gave 17·2, and the Barley 18·8 lbs., against 16·4 lbs. over 30 years in the various root-crops.

We now come to the yield of nitrogen in Leguminous crops, grown under somewhat similar circumstances as to the soil supplies of it. Referring first to the results obtained with Beans, it is seen that, over the first half of the period of 24 years, the average annual yield of nitrogen in the crop was 61·5 lbs. per acre; whilst, over the second 12 years, in 3 of which, however, the crop failed, so that there were only 9 years of Beans, 1 year of Wheat, and 2 years of Fallow, the annual yield was less than half as much, or only 29·5 lbs. per acre. Nevertheless, the average yield over the 24 years without any nitrogenous manure, was 45·5 lbs. per acre per annum. That is to say, under very similar conditions as to soil supply, the highly nitrogenous Leguminous crop, Beans, has yielded over a given area, twice as much nitrogen as either Wheat or Barley, and more than twice as much as the root-crop.

The next results relate to the Leguminous crop, Clover. It is well known that Clover fails when it is attempted to grow it too frequently on the same land; and in the case recorded in the Table, it happened that Clover was obtained in only 6 years out of the 22 for which the yield of nitrogen is given; so that there are included, owing to the failures, 1 year of Wheat, 3 years of Barley, and 12 of Fallow. Notwithstanding this, there was, with the occasional interpolation of the Clover, an average yield, over the 22 years, of 39·8 lbs. of nitrogen per acre with mineral, but without nitrogenous supply.

The last results in the Table relate to the yield of nitrogen per acre per annum, over 32 years of an actual rotation of crops; that is, over 8 courses of 4 years, each course comprising Swedish Turnips, Barley, Clover (or Beans), and Wheat, which, as in the other cases, were grown with a purely mineral manure (in this case superphosphate of lime alone), but without any nitrogenous supply.

The figures show that, when the various crops are thus grown in alternation one with another, instead of each separately year after year, on the same land, the yield of nitrogen is generally greater, and sometimes much greater. Thus, whilst the mineral manured Swedish Turnips, yielded only 18·5 lbs. of nitrogen per acre per annum, when grown year after year on the same land, they yielded 33·3 lbs. when grown in rotation; the Barley yielded 22·4 lbs. when grown continuously, and 23·5 lbs. in rotation; the Beans 45·5 lbs. grown year after year, and only 40·5 lbs. in rotation, but this is very much more than the yield of the continuous Beans in the second half of the period, which was only 29·5 lbs.; the Clover yields an average of 124·5 lbs. in rotation, against only 39·8 lbs. when it was attempted to grow it continuously, and it frequently failed; and the Wheat succeeding the Leguminous crop in rotation, yields 35·9 lbs. against only 22·1 lbs. grown continuously. Lastly, the rotation crops taken together (including *Leguminosæ*), have yielded, over 32 years, an average of 38·6 lbs. of nitrogen per acre per annum, against only about half as much in either

Wheat, Barley, or Roots, grown under the same manurial conditions, that is without nitrogenous supply, but each grown continuously on the same land; whilst, in an exactly corresponding rotation, but with fallow instead of a leguminous crop in the third year, the average annual yield of nitrogen over the 32 years, was only 24·3 lbs.

It is seen, then, that the increased yield of nitrogen in the rotation-crops, was largely due to the interpolation of the *Leguminosæ*, the Clover or the Beans; in part owing directly to the large yields of nitrogen in these crops themselves, but in part to the increased yields in the Wheat immediately succeeding the Leguminous crop, which, especially the Clover, would leave an effective nitrogenous crop-residue, but, in part also, to some effect from this increased crop-residue on the other crops of the course; and lastly, to the fact, that the various crops grown in alternation have different root ranges, and grow during different periods of the season. The Wheat, in fact, yielded nearly as much after the removal of the highly nitrogenous Leguminous crop, as on a corresponding plot left Fallow; from which, therefore, no nitrogen had been removed in the produce in the preceding year.

The next illustrations show more strikingly still, the greater yield of nitrogen in Leguminous than in Gramineous crops, grown under equal soil conditions. They relate to the yield of nitrogen in Barley and in Clover, grown side by side in the same field; and the results are given in Table II.

TABLE II.

Nitrogen per acre per annum, in Barley and Clover, grown in Little Hoosfield, Rothamsted.

			Nitrogen per acre.
			lbs.
1873	Barley	.. ..	37·3
	Clover	.. ..	151·3
1874	Barley	After Barley	39·1
		After Clover	69·4
	Barley after Clover more than after Barley		30·3

The field had grown one crop of Wheat, one crop of Oats, and three crops of Barley in succession with artificial mineral and nitrogenous manures, but without any farm-yard or other organic manure. In 1872, Barley was again sown; on one half alone, and on the other half with Clover. In 1873, Barley was again grown on the one half, but the Clover on the other. The Table shows that the Barley yielded 37·3 lbs. of nitrogen per acre, whilst the three cuttings of Clover contained 151·3 lbs. In the next year, 1874, Barley was grown over both portions: and on the one where Barley had yielded 37·3 lbs. of nitrogen in the previous year, it now yielded 39·1 lbs.; but on the portion where the Clover had yielded 151·3 lbs., the Barley succeeding it yielded 69·4 lbs. That is to say, the Barley yielded 30·3 lbs. more

nitrogen after the removal of 151·3 lbs. in Clover, than after the removal of only 37·3 lbs. in Barley.

The fact is, that the Clover had not only yielded so much more nitrogen in the removed crops, but it had also left the surface soil considerably richer in nitrogen. Thus, in October, 1873, after the removal of the Barley and the Clover, samples of soil were taken from 10 places on each of the two portions, and the nitrogen was determined in the samples from each of 4 of the individual holes separately, in the mixture of the 4, and in the mixture of the samples from the other 6 places. The determinations in the numerous separate samples consistently showed that, to the depth of 9 inches, the Clover-land soil which had yielded so much more nitrogen in the crops, was nevertheless determinably richer in nitrogen than the Barley-land soil, which had yielded so much less. This is sufficiently illustrated by the following figures, showing the mean percentage of nitrogen in the dry fine soil, of the Clover, and of the Barley-land, respectively :—

	Mean per cent. Nitrogen.
In Clover-land soil	0·1566
In Barley-land soil	0·1416

This was the case notwithstanding that all visible vegetable débris had first been removed from the samples. It was further found, that the above- and under-ground vegetable residue picked from the Clover-land samples, was much more in quantity, and contained much more nitrogen, than that from the Barley-land samples.

In 1874, and in 1875, barley only was sown over both portions. In 1876, barley was again sown over the whole of the land, with Clover as well on the portions where it had been grown in 1873 ; but the plant failed in the winter, and gave no crop in 1877. In 1877, Barley was again sown over the whole ; this time with Clover on half of the previously Clover portion, and on half of the previously only Barley portion. In the autumn of 1877, soil samples were again taken ; this time from 4 places on each of the differently cropped portions. The determinations of nitrogen in the surface soils consistently showed, as before, a higher percentage where Clover had grown than where only Barley had grown.

It is, of course, well known in agriculture, that the growth of Clover, which removes much more nitrogen than a cereal crop, increases the produce of a succeeding cereal as if nitrogenous manure had been applied. But what I wish specially to direct attention to is, the fact that a Leguminous crop accumulates a great deal more nitrogen over a given area than a Gramineous one under equal soil conditions.

YIELD OF NITROGEN IN THE CROPS OF A MANURED ROTATION.

Before considering the effects of direct nitrogenous manures on the different crops, it will be well to form some idea of the amount of nitrogen yielded in fairly good crops grown in rotation, with fairly liberal manuring. This point may conveniently be illustrated by the

results given in Table III. (below), which show the amounts of nitrogen in the crops grown in the experimental rotation at Rothamsted, for which a full manure, both mineral and nitrogenous, is applied for the Turnips commencing each course. The whole of the crops, roots and leaves in the case of the Turnips, and both corn and straw in that of the Cereals and the Beans, are removed from the land, and the figures show the average amounts of nitrogen in the crops over 8 courses in each case, that is over a period of 32 years in all.

TABLE III.

Yield of Nitrogen in Crops grown in four-course rotation, with artificial mineral and nitrogenous manures.
8 courses, 32 years, 1852-1883.

	Average yield of Nitrogen per acre per annum.
	lbs.
1. Swedish Turnips	80·6
2. Barley	40·7
3. Clover (2 courses)	167·0
3. Beans (6 courses)	63·6
Average Clover and Beans	89·5
4. Wheat	43·7
Average of all crops	63·6

If we compare the amounts of nitrogen in these crops, for which nitrogenous as well as mineral manures were applied, with those obtained in a corresponding rotation but without nitrogenous manure, as shown in Table I. (p. 3), it is seen that every one of the crops, the Roots for which the manure was directly applied, the Cereals, and the Leguminous crops, all yield much more nitrogen than when no nitrogenous manure was applied. The amounts of nitrogen obtained in the Cereals are about the same as, or perhaps rather less than, in average good crops grown in ordinary farm practice. The amounts obtained in the Turnips are also perhaps rather less than in average good crops, and considerably less than in a good crop of Mangel-Wurzel. The amounts in the Beans are also less than in a good crop of Beans, grown on suitable Bean-land, but the amounts in the Clover are more than in the average of crops grown in ordinary rotation.

Taking the results as they stand, it is seen that, both the Roots and the Leguminous crops accumulate much more nitrogen than either of the Cereals grown in alternation with them. Lastly, whilst the average yield of nitrogen, per acre per annum, over 32 years was, without nitrogenous manure only 38·6 lbs. (see Table I.), it is, with nitrogenous manure, 63·6 lbs.; and compared with this latter amount, it may be mentioned that, in a similarly manured rotation, but with fallow instead of a leguminous crop in the third year, the annual yield of nitrogen was only 39·9 lbs.

PERCENTAGE OF NITROGEN, IN THE DRY SUBSTANCE OF VARIOUS CROPS.

Not only is the yield of nitrogen per acre much less in the Cereal crops, but the percentage of nitrogen in the dry substance of the Gramineous produce is much less than in that of the Leguminous produce. This is illustrated in Table IV. (below), which shows the average percentage of nitrogen in the dry substance of various crops.

TABLE IV.

Average Percentage Nitrogen in the dry substance of various Crops.

	Corn or Roots.	Straw or Leaf.
	Per cent.	Per cent.
Wheat	2·12	0·54
Barley	1·96	0·47
Oats	2·33	0·60
Maize	1·93	
Peas	4·24	1·21
Beans	4·71	1·09
White Turnips	2·25	3·7
Yellow Turnips	2·22	
Swedish Turnips	2·27	4·0
Mangel Wurzel	1·76	2·9
Potatoes	1·00	
HAY.		
Meadow Hay	1·79	
Clover Hay	2·89	

Thus it is seen, that the corn of the Leguminous crops, Beans and Peas, contains more than twice as high a percentage of nitrogen in its dry substance as that of the Gramineous grains. The dry substance of the Leguminous straws, also contains about twice as high a percentage of nitrogen as that of the Cereal straws. Again, the dry substance of Clover-hay contains not far short of twice as much nitrogen as that of Meadow-hay. Lastly, the dry substance of the Roots contains about the same percentage of nitrogen as that of the Cereal grains, but only about half as much as that of the Leguminous corn. The leaves of the Root-crops are, however, high in nitrogen.

The general result is, then, that the *non*-Leguminous crops, especially those of the Gramineous family, are characterised, both by yielding much less nitrogen in their produce over a given area, and by containing a much lower percentage of nitrogen in their dry substance, than the Leguminous crops. Bearing these facts in mind, let us now turn to the consideration of the effects of direct nitrogenous manures on the various crops.

EFFECTS OF NITROGENOUS MANURES IN INCREASING THE PRODUCE OF VARIOUS CROPS.

I need not remind you that, under the conditions in which the crops are grown in ordinary agriculture, nitrogenous manures have very marked effects in increasing the amounts of produce of Wheat, of Barley, of Turnips, of Mangels, and of Potatoes;—that is, of the comparatively low-in-nitrogen *non*-Leguminous crops. For detailed evidence on the point, I may refer you to my former lectures relating to these various crops. But I may recall to mind the fact that—in the case of Wheat and Barley the increased produce consists characteristically of the non-nitrogenous substances starch and cellulose, in that of the Root-crops of the non-nitrogenous substance sugar, and in that of Potatoes of the non-nitrogenous substance starch.

Table V. (p. 10), illustrates very strikingly the influence of nitrogenous manures in increasing the production of the non-nitrogenous constituents of our crops.

The first column of figures shows, the estimated amounts of carbon, per acre per annum, in the total produce of Wheat and of Barley, in the roots of Sugar-Beet and Mangel-Wurzel, in the tubers of Potatoes, and in the total produce of Beans; in each case when grown by a complex mineral manure without nitrogen, and also with the same mineral manures with nitrogenous manure in addition. The second column shows the estimated gain of carbon; that is, the increased amount of it assimilated under the influence of the nitrogenous manures. The third column shows the estimated increased production of total carbohydrates, under the influence of the nitrogenous manures; and the last column the estimated gain of carbohydrates for 1 of nitrogen in manure.

The mode of calculating the amounts of carbon and of carbohydrates is as follows. From the amount of dry substance in the crops, the amounts of mineral matter and of nitrogenous substance are deducted; and the remainder represents the amount of carbohydrates. The amount of carbon in the nitrogenous substance is calculated; and then that in the carbohydrate, on the assumption that, in the Wheat, Barley, and Beans, starch and cellulose are the main products; in the Sugar-Beet and Mangel-Wurzel, cane-sugar, pectine, and cellulose; and in the Potatoes, starch and cellulose. Such estimates can, obviously, only be approximations to the truth; but, accepted as such, they are useful, as conveying some definite impression, of the influence of nitrogenous manures on carbon-assimilation, and on carbohydrate-formation.

As Table V. shows, the calculations are based on the average produce, by the different manures, of Wheat over 20 years, of Barley over 20 years, of Sugar-Beet over 3 years, of Mangel-Wurzel over 8 years, of Potatoes over 10 years, and of Beans over 8 years.

It is thus seen that, independently of the underground growth, the Wheat was estimated to assimilate 988 lbs. of carbon per acre per

annum, under the influence of a complex mineral manure alone; and that the amount was increased to 1,590 lbs. by the addition of 43 lbs. of nitrogen as ammonium-salts, to 2,222 lbs. by 86 lbs. of nitrogen as ammonium-salts, and to 2,500 lbs. by 86 lbs. nitrogen as sodium-nitrate. Accordingly, as shown in the second column, the increased assimilation of carbon was, by 43 lbs. of nitrogen as ammonium-salts 602 lbs., by 86 lbs. as ammonium-salts 1,234 lbs., and by 86 lbs. as sodium-nitrate 1,512 lbs.

TABLE V.

Estimates of the Yield and Gain of Carbon, and of the Gain of Carbohydrates, per acre per annum, in various Experimental Crops, grown at Rothamsted.

	Carbon.		Carbohydrates.	
	Actual.	Gain.	Gain.	For 1 Nitrogen in Manure.
WHEAT 20 years, 1852-1871.				
	lbs.	lbs.	lbs.	lbs.
Mineral Manure	988			
Mineral Manure and 43lbs. Nitrogen as Ammonia..	1590	602	1240	28·8
Mineral Manure and 86lbs. Nitrogen as Ammonia..	2222	1234	2550	29·7
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	2500	1512	3140	36·5
BARLEY 20 years, 1852-1871.				
Mineral Manure	1138			
Mineral Manure and 43lbs. Nitrogen as Ammonia..	2088	950	1992	46·3
SUGAR-BEET 3 years, 1871-1873.				
Mineral Manure	1123			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	2600	1477	3188	37·1
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	3031	1908	4052	47·1
MANGEL WURZEL 8 years, 1876-1883.				
Mineral Manure	759			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	1889	1130	2376	27·6
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	2129	1370	2771	32·2
POTATOES 10 years, 1876-1885.				
Mineral Manure	1021			
Mineral Manure and 86lbs. Nitrogen as Ammonia..	1783	762	1507	17·5
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	1752	731	1416	16·5
BEANS 8 years, 1862 and 1864-1870.				
Mineral Manure	726			
Mineral Manure and 86lbs. Nitrogen as Nitrate ..	992	266	474	5·5

Reckoned in the same way, the increased assimilation of carbon in the Barley was, for 43 lbs. nitrogen as ammonium-salts, 950 lbs. per acre; that is one-and-a-half time as much as by the same application in the case of wheat.

In the Sugar-Beet (the roots only), the increased assimilation of carbon was 1,477 lbs. per acre by the application of 86 lbs. nitrogen as

ammonium-salts, and 1,908 lbs. by 86 lbs. nitrogen as sodium-nitrate. There is, therefore, considerably more increased assimilation of carbon in the produce of Sugar-Beet than in that of Wheat by the same applications of nitrogenous manure.

In Mangel-Wurzel roots the increased assimilation of carbon was 1,130 lbs. by 86 lbs. of nitrogen as ammonium-salts, and 1,370 lbs. by 86 lbs. as nitrate; that is less than in the removed crops (corn and straw) of Wheat, and considerably less than in the removed crops (the roots) of Sugar-Beet.

In the case of the Potatoes, reckoned on the increased production of tubers only (the tops being left on the land), the increased yield of carbon by 86 lbs. of nitrogen as ammonium-salts is 762 lbs. per acre, and by 86 lbs. as sodium-nitrate 731 lbs. That is to say, there is considerably less increased production of starch in Potatoes, than of sugar in Sugar-Beet, or Mangel-Wurzel, by the same applications of nitrogenous manure.

Lastly, in the Leguminous crop, Beans, with its high yield of nitrogen per acre, and the high percentage of nitrogen in its dry substance, the increased assimilation of carbon under the influence of nitrogenous manure was comparatively quite insignificant. Thus, there was, by the application of 86 lbs. of nitrogen as sodium-nitrate, an increased assimilation of carbon of only 266 lbs. per acre; or little more than one-sixth as much as in Wheat, and little more than one-eighth as much as in Sugar-Beet, by the same application.

Turning to the figures in the third column, it is seen that the estimated increased production of the non-nitrogenous carbohydrates, by the use of nitrogenous manures, was very great.

Thus, by the use of 43 lbs. of nitrogen as ammonium-salts, there is an estimated increase of 1,240 lbs. of carbohydrates in Wheat, and of 1,992 lbs. in Barley. By the application of 86 lbs. of nitrogen as ammonium-salts, there was an increased formation of carbohydrates of 2,550 lbs. in Wheat, of 3,188 lbs. in Sugar-Beet, of 2,376 lbs. in Mangel-Wurzel, and of only 1,507 lbs. in Potatoes; and when 86 lbs. were applied as sodium-nitrate, there was an increased production of 3,140 lbs. in Wheat, of 4,052 lbs. in Sugar-Beet, of 2,771 lbs. in Mangel-Wurzel, and of only 1,416 lbs. in Potatoes. Whilst, compared with these amounts, there was, by the same application, an increase of only 474 lbs. of carbohydrates in Beans.

The last column shows the estimated increased amounts of carbohydrates produced for 1 of nitrogen in manure, in the different cases. Thus, when 43 lbs. of nitrogen were applied as ammonium-salts, 1 lb. of nitrogen in manure gave an increased production of 28·8 lbs. of carbohydrates in wheat, and of 46·3 lbs. in Barley; when 86 lbs. nitrogen were applied as ammonium-salts, 1 lb. gave an increase of 29·7 lbs. carbohydrates in Wheat, 37·1 lbs. in Sugar-Beet, 27·6 lbs. in Mangel-Wurzel, and 17·5 lbs. in Potatoes. Again, when 86 lbs. were applied as sodium-nitrate, 1 lb. gave an increase of 36·5 lbs. carbohydrates in Wheat, 47·1 lbs. in Sugar-Beet, 32·2 lbs. in Mangel-Wurzel, 16·5 lbs. in Potatoes, and only 5·5 lbs. in the Leguminous crop—Beans.

It is natural to ask—what is the explanation of the apparently anomalous result, that the crops which are characterised by containing comparatively little nitrogen, and by yielding large amounts of non-nitrogenous products—starch, sugar, and cellulose—are especially benefited by the application of nitrogenous manures; and that, under their influence, they yield greatly increased amounts of those non-nitrogenous bodies?

It is, perhaps, little more than stating the facts in another way to say, as is the case, that the luxuriance, or activity of growth, of all these crops, is very greatly enhanced by nitrogenous manures; and that, since their special products are these non-nitrogenous substances, the natural result of the increased luxuriance is to increase the formation of the bodies which are their essential or characteristic products.

A further possible explanation of the curious results has, however, been suggested.*

Thus, on purely chemical and physiological grounds, and, so far as would appear, without any special reference to the fact that, in the case of our chief starch and sugar yielding crops, the production of those substances is greatly enhanced by the use of nitrogenous manures, it has been suggested that the substance first formed in the chlorophyll-corpuscle, from carbon-dioxide and water, is not starch, but a substance possibly allied to formic aldehyde (CH_2O), which goes to construct proteid, by combining with the nitrogen and sulphur absorbed in the form of salts from the soil, or with the nitrogenous residues of previous decompositions of proteid. It is supposed, however, that starch may, nevertheless, be the first *visible* product of the constructive metabolism; since, unless protoplasm were being formed, no starch could be produced.

This view is partly founded on the consideration of the analogy that would then be established, between the formation of starch and that of the carbohydrate—cellulose; which is by some experimenters supposed to be derived directly from protoplasm.

It is true, that such a supposition is at any rate not inconsistent with the conditions which we have seen to be favourable for the increased production of starch and sugar in agricultural plants. At the same time, it is admittedly at present little more than hypothesis. It would, indeed, require more evidence than is at present available, to establish such a conclusion; whilst there are considerations which would lead us to hesitate to adopt the view in question, without clear experimental proof.

Thus, it seems difficult to suppose, that the undoubted connection in some striking cases, between the amount of nitrogen taken up by the plant, and the amount of starch or sugar formed, is to be explained by an assumption which implies that a chief office of the nitrogenous bodies of plants is to serve as intermediate only, in the transformations

* See Vines' Lectures on the "Physiology of Plants," p. 140, *et seq.*

necessary for the formation of the non-nitrogenous substances. The view does not, however, assume that nitrogen is eliminated from the plant in the process, and so lost.

Then, again, plants such as many of the Leguminosæ, which are characterised by assimilating relatively very large amounts of nitrogen over a given area of land, and by the formation of very large amounts of proteid in proportion to plant surface, produce relatively small amounts of the carbohydrates.

Nor is it irrelevant to refer to the fact that, from theoretical considerations, it was for many years assumed, especially in Germany, in opposition to the teachings of our own numerous direct experiments, that in the animal body the non-nitrogenous substance—fat—was mostly, if not always, produced by the degradation of proteid; the nitrogenous bye-products being for the most part, if not entirely, eliminated from the body as waste matter. It is, however, now indubitably established, at any rate in the cases of the *herbivora* which produce the most fat, that that substance is derived largely, if not exclusively, from the non-nitrogenous constituents of the food—the carbohydrates.

In the case of the supposed transformation in plants, the same prodigal expenditure of the nitrogenous bodies in the formation of the non-nitrogenous is, however, as has been said, not involved.

EFFECTS OF NITROGENOUS MANURES ON LEGUMINOUS CROPS.

Such are the very marked effects of nitrogenous manures in increasing the amounts of produce, and especially in increasing the production of non-nitrogenous constituents, when applied to our *non*-Leguminous, and comparatively low in nitrogen, crops. I have now to illustrate the influence of nitrogenous manures on various Leguminous crops, which, on the other hand, are characterised by containing a high percentage of nitrogen in their dry substance, and by assimilating a large amount of nitrogen from some source over a given area of land. It will be seen that the results to which I have to direct attention will bring to view some very remarkable failures, but also some not less signal and significant successes.

My first illustrations relate to experiments with Beans, grown for many years in succession on the same land—without manure, with a purely mineral manure (consisting of superphosphate of lime, and salts of potash, soda, and magnesia), also with the same mineral manure, and nitrogenous manure in addition, supplied either as ammonium-salts, or as sodium-nitrate. The results are recorded in Table VI. (p. 14).

It is seen that the record relates to a period of 32 years of continued or interrupted experiment with Beans, from 1847 to 1878 inclusive.

The first three columns show the produce of the corn, the second three that of the straw, and the third three that of the total produce, corn and straw together; each under three conditions as to manuring.

TABLE VI.

BEANS.

Grown year after year on the same land, Geescroft Field, Rothamsted.
Results, without Manure, with Mineral Manure, and with Mineral and Nitrogenous Manure.
Produce per acre, each year, in lbs.

Years.	Total Corn.			Total Straw.			Total Produce (Corn and Straw).		
	Unmanured.	Mixed Mineral Manure (including Potash).	Mixed Mineral Manure and Nitrogen. (1)	Unmanured.	Mixed Mineral Manure (including Potash).	Mixed Mineral Manure and Nitrogen. (1)	Unmanured.	Mixed Mineral Manure (including Potash).	Mixed Mineral Manure and Nitrogen. (1)
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1847	1611	1697	1746	2125	1959	2185	3736	3656	3931
1848	1390	1831	2048	1269	1532	1730	2659	3363	3778
1849	2173	(2390)	2250	1641	(2)	1743	3814	(2)	3993
1850	1071	1432	1679	1070	1312	1441	2141	2744	3120
1851	2074	3315	3554	1920	3279	3568	3994	6594	7122
1852	697	855	1007	820	1286	1541	1517	2141	2548
1853	280	462	555	489	802	992	749	1264	1547
1854	365	1423	1266	394	1272	1133	759	2695	2399
1855	987	956	889	770	828	788	1757	1784	1677
1856	755	1627	1568	808	1914	1900	1563	3541	3468
1857	732	660	648	676	644	636	1408	1304	1284
1858	126	640	612	654	1392	1300	780	2032	1912
1859	142	352	401	196	416	498	338	768	899
1860	Fallow								
1861 (3)	(2156)	(2434)	(2509)	(3869)	(4596)	(4742)	(6025)	(7030)	(7251)
1862	513	1014	1479	930	2256	3064	1443	3270	4543
1863	Fallow								
1864	133	1672	1837	960	2568	2468	1093	4240	4305
1865	261	514	1296	704	1080	2180	965	1594	3476
1866	142	316	914	317	628	1190	459	944	2104
1867	49	381	604	280	1252	1360	329	1633	1964
1868	48	384	478	533	930	1203	581	1314	1681
1869	106	926	1308	338	1394	1607	444	2320	2910
1870	458	450	615	516	483	533	974	933	1148
1871	Crop de	stroyed	by severe	winter					
1872	Fallow								
1873	Fallow								
1874	1259	1899	2087	944	1328	1568	2203	3227	3655
1875	1193	882	1114	1674	1988	2576	2867	2870	3690
1876	Fallow								
1877	674	1974	1685	722	1809	1533	1396	3783	3218
1878	148	949	1108	301	1216	1496	449	2165	2604
Average per acre per annum, over each period of 8 years, and the total period of 32 years.									
8 yrs., 1847-1854	1205	1573 (4)	1763	1216	1635 (4)	1792	2421	3208 (4)	3555
8 yrs., 1855-1862	676	960	1013	988	1506	1616	1664	2466	2629
8 yrs., 1863-1870	150	580	881	456	1042	1317	606	1622	2198
8 yrs., 1871-1878	409	713	749	455	793	897	864	1506	1646
32 yrs., 1847-1878	610	937 (5)	1102	779	1231 (5)	1405	1389	2168 (5)	2507
Average per acre per annum, over the years of crop only, each period.									
1st 8 yrs., 8 crops	1205	1573 (6)	1763	1216	1635 (6)	1792	2421	3208 (6)	3555
2nd 8 yrs., 7 crops	773	1097	1158	1129	1721	1847	1902	2818	3005
3rd 8 yrs., 7 crops	171	663	1007	521	1191	1506	692	1854	2513
4th 8 yrs., 4 crops	819	1426	1499	910	1585	1793	1729	3011	3292
32 yrs., 26 crops	751	1162 (7)	1356	958	1526 (7)	1730	1709	2688 (7)	3086

(1) 5 years, 1847-1851, 46 lbs. Nitrogen as Ammonium Salts; 11 years, 1862, 1864-1870, 1875, 1876, and 1878, 86 lbs. Nitrogen as Sodium Nitrate. (2) Accidentally not weighed. (3) Wheat. (4) 7 years, excluding 1849. (5) 31 years, excluding 1849. (6) 7 crops, excluding 1849. (7) 25 crops, excluding 1849.

It should be further explained that, in the first 5 years, the nitrogen applied to the third plot was in the form of ammonium-salts. The effects were, however, so small and irregular, that the application of nitrogenous manure was then suspended for some years; indeed for 10 years, when, it having been observed that nitrates were more beneficial to Leguminosæ than ammonium-salts, sodium-nitrate was applied instead; in amount supplying 86 lbs. nitrogen per acre per annum, or nearly twice as much as had been given as ammonium-salts in the earlier years. This application of the nitrate commenced in 1862; and with some breaks, owing to severe or wet winters, which prevented the seed being sown, or destroyed the plant, it was continued up to 1878, when the experiments were finally abandoned.

Referring to the results, a glance at the Table shows that, independently of fluctuations obviously due to season, there were frequent entire failures, which were also more or less due to season, but which were also dependent partly on the conditions induced in the land by the continuous cropping with this plant; which, as is the case with most Leguminosæ, is very susceptible to parasitic attacks of various kinds, when the conditions of growth are not normal and favourable. Indeed, it is seen that, even when there was not absolute failure, there was a general tendency to decline in yield, and then to recover again, more or less, after a break. This was somewhat marked after a year of Fallow in 1860, and the growth of Wheat in 1861; after which there was, in 1862, fair produce, especially on the third plot, where the nitrate was now applied. The land was again Fallow in 1863, and this was again followed by improved growth; after which there was declining produce for a number of years to 1870 inclusive, and again recovery in 1874, after 3 years of Fallow. This general view of the results is of interest, as fixing attention on the great tendency to failure of this Leguminous crop, when grown year after year on the same land.

Turning to the effects of the different manures, it will suffice to direct attention to the last three columns of the Table, which record the amounts of total produce, that is corn and straw together, under each of the three conditions as to manuring.

Disregarding the results of the first year, when the unmanured plot gave relatively high produce, it is seen that, although there are irregularities, there is generally, whether the crops are large or small, a considerable increase of produce by the use of the mineral manure containing potash, but there is comparatively little further increase by the addition of nitrogenous to the mineral manure. Thus, as shown in the bottom division but one of the Table, the average annual total produce, over the 32 years (which however included 7 without any Bean crop) was—without manure, 1,389 lbs., with the mineral manure alone 2,168 lbs., and with the mineral and nitrogenous manure together 2,507 lbs. That is to say, whilst the mineral manure without nitrogen gave an average annual increase of 779 lbs., the addition to it of nitrogenous manure only further raised the produce by 339 lbs.

Or if, instead of taking the average of the 32 years, we take it only over the 26 years in which there was any Bean crop, the average total produce was—without manure 1,709 lbs., with purely mineral manure 2,688 lbs., and with the mineral and nitrogenous manure together, 3,086 lbs.; that is, there was an annual average increase of 979 lbs. by the mineral manure containing potash, and of only 398 lbs. more by the addition of nitrogenous manure.

The details further show that—without manure, the total produce of two of the last 8 years was only exceeded three or four times during the whole period, namely during the first five years;—with mineral manure alone, the total produce of 2 of the last 8 years was only exceeded four or five times;—and with the mineral and nitrogenous manure together, the total produce of 2 of the last 8 years was only exceeded six times. Indeed, on both of the manured plots, the average total produce over the last 4 years of actual crop, was nearly as much as the average of the first 8 years of crop. Thus, with the purely mineral manure, the average total produce of the first 8 years was 3,208 lbs., and over the last 4 years of crop it was 3,011 lbs., and with the mineral and nitrogenous manure, it was over the first 8 years 3,555 lbs., and over the last 4 years of crop 3,292 lbs. It will be seen further on, that the average annual yield of nitrogen was also nearly as great over the last 4 years, as over the first 8 years, of crop.

It may be observed that nitrogen supplied as ammonium-salts to the highly nitrogenous Leguminous crops, seldom gives any increase, and is sometimes injurious, in the year of application; though some benefit may afterwards result from the residue after the ammonia has been converted into nitric acid. Even nitrates, however, directly applied as manure, are very uncertain in their action, and at any rate yield very much less increase of produce with the highly nitrogenous Leguminosæ, than with the Gramineæ, and crops of other families, yielding produce of low percentage of nitrogen in its dry substance, and appropriating comparatively little nitrogen over a given area of land.

To this point I shall have to refer in some detail further on, but in the meantime it is to be specially noted, that whilst the Cereal crops may be successfully grown for many years in succession on the same land, provided only that mineral and nitrogenous manures are liberally supplied, the Leguminous crop—Beans, gradually fails when so grown; and although characteristically benefited by mineral manures containing potash, neither these alone, nor a mixture of mineral and nitrogenous manure, has sufficed to maintain even fair growth for a number of years in succession.

The result is, however, not entirely due to deficiency in the supply of constituents within the soil, but is also in a considerable degree dependent on the fact that, by the continuous growth of the crop, with its special habit, and range of roots, the surface soil acquires a close and unfavourable condition, and a somewhat impervious pan is formed below. The improved result in the later years, with the inter-

vention of Fallow, further illustrates the fact that the previous failures were not wholly due to exhaustion.

The next Table, VII. (below), shows the amounts of nitrogen in the Bean crops, the produce of which we have been considering.

TABLE VII.

BEANS.

Grown year after year on the same land, with different Manures, in Geescroft Field, Rothamsted.

Yield of Nitrogen, lbs. Average per acre, per annum, 8-year periods.

Periods.	In Corn.			In Straw.			In Total Produce (Corn and Straw).		
	Unmanured.	Mixed Mineral Manure (including Potash).	Mixed Mineral Manure and Nitrogen. (1)	Unmanured.	Mixed Mineral Manure (including Potash).	Mixed Mineral Manure and Nitrogen. (1)	Unmanured.	Mixed Mineral Manure (including Potash).	Mixed Mineral Manure and Nitrogen. (1)
Average per acre per annum, over each period of 8 years, and the total period of 32 years.									
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
8 yrs., 1847-1854	39·0	48·4 (2)	54·5	9·4	11·8 (2)	14·5	48·4	60·2 (2)	69·0
8 yrs., 1855-1862	18·3	24·4	26·5	7·0	9·9	10·3	25·3	34·3	36·8
8 yrs., 1863-1870	5·1	16·0	26·4	4·1	7·5	8·7	9·2	23·5	35·1
8 yrs., 1871-1878	13·0	21·2	22·3	3·4	5·5	6·4	16·4	26·7	28·7
32 yrs., 1847-1878	18·9	26·8 (3)	32·4	5·9	8·6 (3)	10·0	24·8	35·4 (3)	42·4
Average per acre per annum, over the years of crop only, each period.									
1st 8 yrs., 8 crops	39·0	48·4 (4)	54·5	9·4	11·8 (4)	14·5	48·4	60·2 (4)	69·0
2nd 8 yrs., 7 crops	20·9	27·9	30·3	8·0	11·3	11·8	28·9	39·2	42·1
3rd 8 yrs., 7 crops	5·8	18·3	30·1	4·6	8·5	9·9	10·4	26·8	40·0
4th 8 yrs., 4 crops	26·0	42·4	44·5	6·7	10·9	12·9	32·7	53·3	57·4
32 yrs., 1847-1878 } 26 crops }	23·2	33·3 (5)	39·9	7·3	10·6 (5)	12·3	30·5	43·9 (5)	52·2

(1) 5 years, 1847-1851, 46 lbs. Nitrogen as Ammonium Salts; 11 years, 1862, 1864-1870, 1875, 1876, and 1878, 86 lbs. Nitrogen as Sodium Nitrate. (2) 7 years, excluding 1849. (3) 31 years, excluding 1849. (4) 7 crops, excluding 1849. (5) 25 crops, excluding 1849.

General Note.—In the second 8 years, the land was fallow in 1860, and wheat was grown in 1861; in the third 8 years, 1863 was fallow; and in the fourth 8 years, the crop failed in 1871, and the land was lef. fallow in 1872, 1873, and 1876.

The Table is on the same plan as that relating to the produce, but instead of results for every year of the 32, there are now given only averages, in the upper division for the four 8 yearly periods, and for the total period of 32 years; and in the lower division for the years of crop only, within each period. As in Table VI., the first three columns give for each of the three conditions as to manuring, the results for the corn, the second three for the straw, and the last three for the total produce, corn and straw together. It will suffice to direct attention to these last results.

Referring to the figures in the upper division, it may be observed that, notwithstanding there were 6 blank years, and 1 year of wheat, out of the 32, and notwithstanding that the produce declined much, and gave on the whole much less than the average obtained under ordinary agricultural conditions, yet the average yield of nitrogen in the

crops grown without any supply of it was much more than in either of the Cereals, the Root-crops, or Potatoes, grown under similar conditions.

Thus, as the bottom line of the upper division shows, there was an average, over the 32 years, of 24·8 lbs. of nitrogen, per acre per annum, in the crops without any manure, but of 35·4 lbs. with the mineral manure without nitrogen; whilst the amount was raised to only 42·4 lbs. by the addition of nitrogenous manure. Over the first 8 years, however, the yield was very much higher, being for the three plots, respectively, 48·4, 60·2, and 69·0 lbs. Over the second period of 8 years the average was not far from that of the whole 32 years; but over the third and fourth periods it was much less.

As in the case of the total produce itself, so also in that of the nitrogen in the total produce, if we take the averages of the years of crop only, as given in the bottom division of the Table, we have a much higher average yield per annum over the 4 years of crop of the last 8 years, than over the years of crop of either the second or the third period of 8 years. Indeed, on the two manured plots, there is an average annual yield of nitrogen per acre, over the 4 years of crop during the last 8 years, not far short of the average of the first 8 years. Thus, with the purely mineral manure, there is an average annual yield of nitrogen over the first 8 years of 60·2 lbs., and over the 4 years of crop of the last 8 years, of 53·3 lbs.; and with the mineral and nitrogenous manure together, over the first 8 years, of 69·0 lbs., and over the 4 years of crop of the last 8 years, of 57·4 lbs.

That is, with the intervention of Fallow, we have, though not good agricultural crops, yet really large yields of nitrogen, compared with those obtained in many of the preceding years; and very large yields without any supply by manure, compared with those obtained under the same conditions with any of the *non*-Leguminous crops. It would appear probable, therefore, that if a suitable mechanical condition of the land could have been maintained, fair crops, and large yields of nitrogen, would also have been maintained.

Upon the whole, then, although the crop practically failed, when it was attempted to grow it year after year on the same land, it nevertheless accumulated, in its above-ground produce, much more nitrogen over a given area than the crops of the other families, but was little benefited by an artificial supply of nitrogen.

I have now to record a still greater failure, with another crop of the Leguminous family—namely, Trifolium pratense, or Red Clover. The results are summarised in Table VIII. (p. 19).

The Table is headed Red Clover sown frequently on the same land; and the first column shows that the period of experiment was 29 years, from 1849 to 1877 inclusive. But the details show that, although Clover was sown 15 times, in only 7 of the 29 years was any Clover-crop obtained; whilst about one-fifth of the produce of the whole series of years was yielded in the first year, 1849. It is, indeed, well known in agriculture, that Clover will not grow, under ordinary conditions, more

frequently than once in a certain number of years, which varies according to soil and other circumstances, but is seldom so few as four, and frequently as much as 8 years.

TABLE VIII.

RED CLOVER.

Sown frequently on the same land, in Hoosfield, Rothamsted.
Total Produce, per acre per annum; Clover as Hay, other Crops Corn and Straw together.

Year.	Description of Crop.	SERIES 1. Mineral Manure alone.	SERIES 2. Mineral and Nitrogenous Manures.
		lbs.	lbs.
1849	Clover	10214	10326
1850	Wheat	(6261)	(6345)
1851	Clover	2309	2368
1852	Clover	5895	4914
1853	Clover	No crop.	No crop.
1854	Fallow		
1855	Clover	1281	2606
1856	Fallow		
1857	Fallow		
1858	Barley	(6598)	(7578)
1859	Clover	2752	3087
1860	Clover	No crop.	No crop.
1861	Fallow		
1862	Barley	(5745)	(6730)
1863	Fallow		
1864	Clover	No crop.	No crop.
1865	Clover	2467	4500
1866	S. 1 Clover, S. 2 Barley ..	No crop.	(2974)
1867	Fallow		
1868	Clover	No crop.	No crop.
1869	Clover	No crop.	No crop.
1870	Barley	(3328)	(3312)
1871	Clover	No crop.	4085
1872	Fallow		
1873	Fallow		
1874	Clover	No crop.	Fallow.
1875	Clover	4277	Fallow.
1876	Fallow		
1877	Barley	(1864)	(1864)
	SUMMARY. PRODUCE.		
29 years, 1849-1877.. ..	Total	52991	60689
	Average	1827	2093
Years of Crop only.. ..	Average	4416	4668
Years of Clover only (7) ..	Total	29195	31886
	Average	4171	4555
	SUMMARY. NITROGEN (Estimated).		
29 years, 1849-1877.. ..	Total	929·4	1043·1
	Average	32·0	36·0
Years of Crop only.. ..	Average	77·5	80·2
Years of Clover only (7) ..	Total	700·7	765·3
	Average	100·1	109·3

The second column shows that, owing to the failure of the Clover, sometimes a cereal crop, Wheat or Barley, was sown; but more frequently the land was left Fallow. The produce of Wheat, or of Barley, is given between brackets.

The amounts of produce entered in the column headed Series 1, are, in each case, the means of those on 3 plots, each of which occasionally received a mineral manure containing potash; and the results given in the column, Series 2, are also the means of 3 plots, each with the mineral, and nitrogenous manures in addition, occasionally applied.

It is seen that very large crops of Clover were obtained in the first year, 1849; less than one-quarter as much in the third year, 1851; and in the fourth year about half as much as in the first. There was then no more Clover until the seventh year, when there was very little. More or less was afterwards obtained in the eleventh, seventeenth, twenty-third (on one plot), and lastly (on one plot) in the twenty-seventh year; but, in no case excepting in the fourth year, was the amount of produce half as much as in the first year.

Comparing the results without, and with, the nitrogenous manure, it is shown, in the summary at the bottom of the Table, that the average annual total produce, of Clover-hay, or of other crops, was, reckoned over the 29 years, 1827 lbs. without, and 2093 lbs. with, the nitrogenous manure; and, reckoned in the same way, the average annual yield of nitrogen was, without nitrogenous manure 32 lbs., and with it 36·0 lbs. Reckoned, however, over the years of crop only, the yield of nitrogen in the Clover and other crops, was, 77·5 lbs. per acre per annum without, and 80·2 lbs. with, the nitrogenous manuring. Or, reckoning the nitrogen in the Clover alone, and only over the years when it gave any crop, the average annual yield of it over those 7 years was, without nitrogenous manure 100·1 lbs., and with it, 109·3 lbs. There was, therefore, comparatively little increase, either in the produce, or in the yield of nitrogen, by the use of nitrogenous manures.

To conclude in regard to these experiments:—The attempt to grow Clover year after year on ordinary arable land, by means of such mineral manures as increase the luxuriance of growth when there is a fair plant, or even by the addition to these of nitrogenous manures, has entirely failed. In view of this failure to grow the crop continuously on ordinary arable land, the next results to which I have to call attention are of much interest and significance.

GROWTH OF RED CLOVER, YEAR AFTER YEAR, ON RICH GARDEN SOIL.

In 1854, after it seemed clear that the plant would not continue to grow on the arable land, Clover was sown in a garden, only a few hundred yards distant from the experimental field, on soil which had been under ordinary kitchen-garden cultivation for probably two or three centuries. It is remarkable that, under these conditions, the crop has grown luxuriantly almost every year since; this year, 1889, being the 36th season of the continuous growth. Further particulars

will be given on the point presently, but it may here be premised that, at the commencement, the percentage of nitrogen in the surface soil of the garden was at least four times as high as in that of the arable soil in the field, and it would doubtless be richer in all other matters also. Indeed, it is probable that the subsoil of the garden, below the first 9 inches of depth, would be as rich, and perhaps richer than the surface soil of the field. Table IX. (below), gives the results for 35 of the 36 years of experiment with Clover on the rich garden soil.

TABLE IX.

RED CLOVER.

Grown year after year on Rich Garden-soil, The Garden, Rothamsted.
Hay, Dry Matter, Mineral Matter, and Nitrogen, per acre, per annum.

Years.	Number of Cuttings.	As Hay.	Dry Matter.	Mineral Matter.	Estimated Nitrogen.	Dates of Sowing Seed.
		lbs.	lbs.	lbs.	lbs.	
1854	2	5,191	4,326	435·0	124·6	1854, March 29.
1855	3	18,113	15,094	1560·0	434·7	
1856	2	11,027	9,190	1115·5	264·6	
1857	3	14,855	12,379	1384·0	356·5	
1858	2	7,608	6,340	792·0	182·6	
1859	2	6,227	5,189	636·5	149·4	
1860	1	8,679	7,233	806·0	208·3	1860, May.
1861	2	13,353	11,128	1285·0	320·5	
1862	2	10,042	8,368	990·5	241·0	
1863	2	11,798	9,832	971·0	283·2	
1864	2	5,500	4,583	446·0	132·0	
1865	1	2,044	1,704	189·5	49·1	1865, April 22.
1866	2	10,456	8,713	907·5	250·9	
1867	2	6,748	5,624	573·0	162·0	
1868	1	991	826	106·0	23·8	1868, April 29.
1869	2	4,183	3,486	387·0	100·4	
1870	1	1,741	1,451	148·0	41·8	
1871	1	4,513	3,761	458·0	108·3	1871, April 10.
1872	2	10,142	8,452	896·5	243·4	
1873	2	9,287	7,740	772·0	222·9	
1874	3	5,899	4,916	539·5	141·6	1874, May 4, and July 7.
1875	1	2,731	2,276	229·5	65·5	1875, July 13, and Sept. 22.
1876	2	3,517	2,931	278·5	84·4	1876, Sept. 1 (died in winter).
1877	1	3,533	2,944	325·5	84·8	1877, May.
1878	3	13,416	11,180	1335·5	322·0	
1879	1	2,738	2,282	427·5	65·7	1879, May 21.
1880	2	5,742	4,785	643·0	137·8	1880, April 17.
1881	2	4,262	3,552	380·0	102·3	1881, April 29 (mended).
1882	3	6,433	5,361	641·0	154·4	1882, April 16 (mended).
1883	1	2,716	2,264	314·5	65·2	1883, May 17.
1884	3	9,990	8,325	862·5	239·8	
1885	3	6,511	5,426	615·0	156·3	
1886	1	2,702	2,252	313·0	64·8	1886, April 14.
1887	2	3,287	2,739	264·0	78·9	1887, April 21 (mended).
1888	1	1,841	1,535	210·5	44·2	1888, April 13 (mended June 12).
		SUMMARY.	Averages.			
10 years, 1854–'63		10,689	8,908	1002·5	256·5	
10 years, 1864–'73		5,561	4,634	488·6	133·4	
10 years, 1874–'83		5,099	4,249	506·5	122·4	
5 years, 1884–'88		4,866	4,055	453·0	116·8	
35 years, 1854–'88		6,795	5,663	635·4	163·1	

The first column after the dates, shows the number of cuttings each year, the second the amounts of produce per acre, reckoned in the condition of dryness as hay, the third the amount of dry substance, the fourth that of the mineral matter, and the last the estimated amounts of nitrogen per acre in the crops. At the bottom of the Table are given the average annual results over periods of 10, 10, 10, 5, and 35 years. I shall confine attention to the amounts of produce reckoned as hay, and to the estimated amounts of nitrogen in the produce.

It should be stated that, as the garden-clover plot is only a few yards square, calculations of produce per acre can only give approximations to the truth; but it is believed that they can be thoroughly relied upon so far as their general indications are concerned. It may be added that five times during the whole period, gypsum has been applied to one-third, and a mineral manure containing potash, but no nitrogen, to another third of this plot.

Casting the eye down the column of produce as hay, it is seen at a glance that, excepting a few occasional years of very high produce during the later periods, the amount of crop is very much greater during the first, than during either of the subsequent periods of 10 or 5 years. In fact, as is seen at the foot of the Table, there was an average annual produce equal to 10,689 lbs. of hay, over the first period of 10 years, but of only 5,561 lbs. over the second, and 5,099 lbs. over the third, and of only 4,866 lbs. over the last 5 years.

Now, even these latter amounts correspond to what would be considered fair, though not large crops, when Clover is grown in an ordinary course of rotation, once only in 4, or in 8 years, or more; so that the produce in the earlier years on this rich garden-soil, was very unusually large. Indeed, the average annual produce over the whole period of 35 years, namely 6,795 lbs.—more than 3 tons of hay—would be a very good yield for the crop grown only occasionally in the ordinary course of agriculture.

But it is when we look at the figures in the last column of the Table, which show the estimated amounts of nitrogen in the crops, that the importance and significance of these results obtained on rich garden-soil, are fully recognised; and this is especially the case when they are compared with those obtained on ordinary arable land.

Thus, whilst the amount of nitrogen in average crops of Wheat, Barley, or Oats, will be from 40 to 50 lbs. per acre, of Beans about 100 lbs., of Meadow Hay about 50 lbs., and Clover Hay grown occasionally in rotation little more than 100 lbs.;—here, on this rich garden-soil, the produce of Clover has, in one year contained more than 400 lbs. of nitrogen, in three years more than 300 lbs., in several more than 200 lbs., and in only eleven years of the 35 less than 100 lbs.

In fact, as the figures at the bottom of the Table show, the estimated average annual yield of nitrogen in the above-ground growth was—over the first 10 years 256 lbs., over the second 10 years 133 lbs., over the third 10 years 122 lbs., over the last 5 years 117 lbs., and over the whole period of 35 years 163 lbs.; whilst, as the details show, the

yield in the 31st year (1884) was about 240 lbs., and in the 32nd year 156 lbs. of nitrogen.

Further, the average over the third 10 years of the continuous growth (122 lbs.), was about as much as in a fair average crop grown occasionally under the ordinary conditions of agriculture.

There would seem, then, to be clearly indicated, a soil source of failure on the arable-land, and a soil source of success on the garden-soil.

The results given in Table X. (below) will throw some further light on this point. It shows the percentage of nitrogen in the first 9 inches of depth of the garden-soil, in 1857 and in 1879, between which periods the growth of 21 years had been removed.

It also shows the estimated amounts of nitrogen per acre in the surface soil at the two periods, and the reduction in the amount during the 21 years.

TABLE X.

RED CLOVER.

Grown on Rich Garden Soil.
Nitrogen, per cent. and per acre, in the fine soil, dried at 100° C.
(First 9 inches of depth).

	1857.	1879.	Difference.
	Per cent. 0·5095	Per cent. 0·3634	Per cent. 0·1461
	lbs.	lbs.	lbs.
Per acre .. .. Total ..	9,528	6,796	2,732
Per acre per annum (21 years)			130

It may be mentioned, that the percentage of nitrogen given for the sample collected in October, 1857, is the mean of duplicate or more determinations, made in 1857, in 1866, and again in 1880; and it is almost identical with the results obtained at the latest of these dates.

The first point to notice is, that the first 9 inches of depth of this rich garden-soil contained more than half a per cent. of nitrogen; that is, nearly four times as much as the average of the Rothamsted arable soils, and nearly five times as much as the exhausted arable Clover-land soil where the crop failed. It is, of course, true, that the garden-soil would be correspondingly rich in all other constituents; but some portions of the arable soil where the Clover failed, had received much more of mineral constituents by manure than had been removed in the crops.

The result given for 1879 is the mean of determinations made on three separate samples, for which the determinations agreed very well. The results can leave no doubt that there had been a great reduction in the stock of nitrogen in the surface-soil since 1857. The reduction amounts to nearly 29 per cent. of the whole in the 21 years; and, reckoned per acre, as shown in the bottom line of the Table, it corresponded to a loss of 2,732 lbs. during the 21 years; and, although, as

has been seen, fairly average, and even good crops, were still grown, it is obvious that coincidently with this great reduction in the stock of nitrogen in the surface-soil, there has been a very marked reduction in the Clover-growing capability of the soil.

On this point it may be mentioned that, whilst fresh seed was only sown four times during the first 17 of the 35 years, it has been fully or partially sown 16 times during the last 18 years. It is obvious, therefore, that the plant was able to stand very much longer in the earlier than in the later condition of the soil. Indeed, both the reduced persistence of the plant, and the reduced produce, have been coincident with a considerable reduction in the stock of nitrogen in the soil.

The question arises—what relation does the amount of nitrogen lost by the soil, bear to the amount taken off in the crops?

It is admittedly necessary to accept with some reservation results of calculations of produce per acre, from amounts obtained on a few square yards, but the general indications may doubtless be trusted. Such estimates show more than 160 lbs. of nitrogen to have been removed per acre per annum in the crops, over the 21 years; whilst the estimated loss of the surface-soil corresponds to about 130 lbs. per acre per annum. That is to say, the loss by the surface-soil is sufficient to account for rather more than three-fourths of the amount of nitrogen removed in the crops.

There is, however, evidence leading to the conclusion that, in the case of soils to which excessive amounts of farmyard manure are applied, as, for instance, to such a garden soil, there may be some loss by the evolution of free nitrogen; and obviously so far as this may have occurred in the garden soil, there will be the less of the ascertained loss to be credited to assimilation by the growing Clover.

On the other hand, it is known that when growing on ordinary arable soil, the Clover plant throws out a large amount of feeding root in the lower layers; and although in the case of so rich a surface soil the plant may derive a larger proportion of its nutriment from that source, we must at the same time suppose that it has also availed itself of the resources of the subsoil. Unfortunately, in 1857 samples were only taken to the depth of nine inches, so that no comparison can be made of the condition of the subsoil at the two periods. It may be observed, however, that in 1879 the second nine inches showed about three times as high a percentage of nitrogen as the subsoils of the arable field at the same depth; indeed nearly twice as high a percentage as some of the exhausted arable surface-soils. It cannot be doubted, therefore, that the subsoil of the garden plot has contributed nitrogen to the Clover crops.

Here then, notwithstanding the very little effect of direct nitrogenous manures, on either the Beans or the Clover, on the ordinary arable land, there would seem to be very clear evidence of a soil-source of, at any rate much, if not indeed of the whole, of the enormous amounts of nitrogen assimilated over a given area by the Clover growing on the rich garden soil.

PRODUCE OF NITROGEN IN THE MIXED HERBAGE OF GRASS LAND.

The results in Table XI. afford evidence in the same direction.

TABLE XI.

EXPERIMENTS ON THE MIXED HERBAGE OF PERMANENT GRASS LAND.

The Park, Rothamsted.

Results showing the effects of Potash, on the development of Leguminosæ, and on the yield of Nitrogen in the crops.

Plots.	Conditions of Manuring.	Mean per cent. according to botanical separations at 6 periods, 1862, '67, '71, '72, '74, '75.			Average produce per acre per annum, 20 years, 1856-'75, according to mean per cent. of the 6 separations.			Average Nitrogen per acre per annum.		
		Gramineæ.	Leguminosæ.	Other Orders.	Gramineæ.	Leguminosæ.	Other Orders.	10 years 1856-1865.	10 years 1866-1875.	20 years 1856-1875.
		p. c.	p. c.	p. c.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
3	Unmanured	70·94	8·17	20·89	1690	195	498	35·1	30·9	33·0
4-1	Superphosphate*	68·17	5·68	26·15	1699	142	652	35·7	31·6	33·6
8	Complex Min. Man.†	73·71	8·43	17·86	2489	285	603	54·4	38·5	46·5
7	Complex Min. Man.‡	66·92	19·13	13·95	2649	757	552	55·2	58·0	56·6

* Plot 4-1, botanical separations at 4 periods only, namely 1862, 1867, 1872, and 1875.
† Including Potash, 6 years, 1856-61, excluding Potash, 14 years, 1862-1875.
‡ Including Potash every year.

As stated in the title of the Table, the results show, in the case of experiments on the mixed herbage of grass-land, the effects of potash on the development of the Leguminosæ, and on the yield of nitrogen in the crop. Results are given for four plots—one without any manure; one with superphosphate of lime alone; one with a complex mineral manure, including potash for six years, but excluding potash for the succeeding 14 years; and lastly, one with the complex mineral manure, including potash every year of the twenty.

The first set of three columns shows the average percentage of gramineous, leguminous, and miscellaneous herbage, in the produce, according to botanical separations made in six, or in four seasons, as stated; the second set the average produce per acre over 20 years, of each of these descriptions of herbage; and the last three columns show the amounts of nitrogen, per acre per annum, in the mixed produce, over the first 10, the second 10, and the total period of 20 years.

It is seen that on plot 8, with only a temporary supply of potash, the percentage of leguminous herbage in the produce is higher than on plot 4-1 with superphosphate of lime alone; but that, on plot 7, with the continuous supply of potash, it is more than twice as high. Thus, the percentage of leguminous herbage is—on plot 4-1, 5·68; on plot 8, 8·43; but on plot 7, 19·13.

The middle column of the second division shows that the estimated amounts of leguminous herbage per acre per annum were—on plot 4-1 without any potash 142 lbs., on plot 8 with partial supply of potash 285 lbs., and on plot 7 with the continuous supply 757 lbs.

Turning to the yield of nitrogen on the different plots, it is seen that the amounts are almost identical without manure, and with superphosphate of lime alone, namely, about 33 lbs. per acre per annum. On plot 8, where a complex mineral manure, including potash six years, but excluding it fourteen years, was employed, the yield of nitrogen is raised to 46·5 lbs.; and on plot 7, which received the mixed mineral manure, including potash every year of the twenty, the yield is 56·6 lbs. per acre per annum. Further, without manure, and with superphosphate of lime alone, there was a decline in the yield of nitrogen in the later, compared with the earlier years. With the mineral manure, including potash in the first six years only, there was a much more marked decline. With the mineral manure, including potash every year, there was, on the other hand, even a slight tendency to an increased yield of nitrogen, in the later years.

Thus, then, it is estimated that the plot receiving potash every year, yielded over a period of twenty years, an average of 23·6 lbs. more nitrogen per acre per annum than the unmanured plot, and this increased yield was associated with an increased growth of Leguminous herbage. Whence comes the 23·6 lbs. more nitrogen annually taken up per acre on the mineral manured than on the unmanured plot? The results in Table XII. will afford evidence on this point.

TABLE XII.

PERMANENT MEADOW LAND SOILS.

Nitrogen, per cent. and per acre, in fine soil, dried at 100° C.

		1870.	1876.	1878.
		Per cent.	Per cent.	Per cent.
Plot 3.	Unmanured	0·2517	0·2466	
Plot 7.	Mixed Mineral Manure, including Potash ..		0·2236	0·2246
	Difference		0·0230	
			lbs.	
	Difference per acre { Total 20 years		506·0	
	{ Average per annum ..		25·3	

After 20 years of continuous experiment, samples of soil were taken at three places on each of the experimental plots, and the Table shows the means of determinations of nitrogen in the surface-soils of the unmanured plot, and of the plot receiving the complex mineral manure (including potash), every year. Some control results are also given. Thus, determinations made in samples of the unmanured soil collected in 1870, control those in the samples collected in 1876, after the crops of five more years had been removed; and, again, the results obtained on samples collected from the mineral manured plot in 1878, control and confirm those obtained on the samples taken in 1876.

Referring to the main figures, those relating to the samples taken in 1876, it is seen, that whilst the percentage of nitrogen in the surface-soil of the unmanured plot was 0·2466, it was in that of the mineral

manured plot, which had yielded so much more nitrogen in the crops, only 0·2236 per cent., or nearly one-tenth less.

Calculated per acre, the surface-soil of the mineral manured plot, to the depth of nine inches, contained, at the end of the twenty years, 506 lbs. less nitrogen than that of the unmanured plot to the same depth; corresponding to an annual reduction of 25·3 lbs. per acre per annum.

Without pretending to claim absolute accuracy for such results, and such calculations, it is, to say the least, a very remarkable coincidence, that whilst the estimated increased yield of nitrogen per acre per annum, in the mineral manured crop was 23·6 lbs., the estimated increased loss of nitrogen by the surface soil should be 25·3 lbs. per acre per annum.

In reference to the fact that, according to the results, the resources of the surface soil would seem to have been mainly, if not wholly, drawn upon, it should be observed, that the potash of artificial manures is almost exclusively retained in the superficial layers of the soil, and that the leguminous plant that was the most prominently developed was the *Lathyrus pratensis*, which, although it has also deep roots, throws out an enormous quantity of feeding root near the surface; whilst the prominent plants of other families were also those characterised by superficial rooting.

Here, again, then, in these results with the mixed herbage of grass land, as in those with the Clover on the rich garden-soil, there seems to be clear indication that the soil is an important source of nitrogen to Leguminosæ.

The next illustrations will bring to view the curious result that, on soil where one leguminous plant has practically failed, another plant of the same family may grow luxuriantly, and in some way obtain very large amounts of nitrogen.

RED CLOVER GROWN AFTER BEANS.

The experiments to which I have now to direct attention, were made in the field which had been devoted to experiments on the growth of beans for a period of 32 years; but which, as has been seen, so far failed that an average crop was seldom obtained; whilst the amount of nitrogen taken up over a given area, though still much more than in *non*-Leguminous crops grown under similar conditions, was, after the first few years, much below the amount in a fairly average Bean-crop. After the cessation of the experiment with Beans in 1878, the land was left fallow for between four and five years, to 1882 inclusive, when Grass-seeds were sown, but failed. On this land, on which the attempt to grow the Leguminous-crop—*Beans*—had been abandoned, Barley and Clover were sown in the spring of 1883.

Before considering the results of this new experiment, it will be well briefly to call attention to the direct experimental evidence as to the condition of the soils. Thus, in April, 1883, before the Barley and Clover were sown, the surface-soil (free of stones, and reckoned

dry) of the plot which had been entirely unmanured during the 32 years of the experiments with the Beans, contained 0·0993 per cent. of nitrogen, that of the mineral manured plot 0·1087 per cent., and that of the plot which had received both the mineral and nitrogenous manure 0·1163 per cent., amounts which show considerable nitrogen exhaustion of the surface-soil.

Also in 1883, the nitrogen as nitric acid was determined in samples, each of 9 inches of depth, down to a total depth of 72 inches. In the case of several plots, the results show, calculated per acre, that the total amount of nitrogen as nitric acid to the depth of 8 times 9 inches, or 72 inches in all, was 27·95 lbs. in the unmanured plot, 20·72 in that with purely mineral manure, and 25·38 lbs. in that of the plot which had received both mineral and nitrogenous manure. In the soil of the farm-yard manure plot, on the other hand, the amount was about twice as much—namely 50·46 lbs. Excluding this last result, it may be said that the amounts of nitrogen already existing as nitric acid, to the depth determined, were very small.

These, then, were the conditions of the soil when the Barley and Clover were sown in the spring of 1883. The Clover grew very luxuriantly from the first, so much so as considerably to interfere with the growth of the Barley.

Table XIII. (below), shows the amounts of nitrogen per acre in the Barley and Clover in 1883, and in the Clover in 1884 and 1885.

TABLE XIII.

BARLEY AND CLOVER, GROWN AFTER BEANS.

Geescroft Field.

Nitrogen removed per acre in the Crops.

Previous Condition of Manuring.	1883. Barley and Clover.	1884. Clover.	1885. Clover.	Total.
	lbs.	lbs.	lbs.	lbs.
Without Manure	45·0	183·2	52·7	280·9
Mineral Manure and some Nitrogen ..	57·2	193·1	79·9	330·2
Mineral Manure only	59·3	206·4	81·6	347·3

It should be stated that the plots, the yield of nitrogen of which is here given, do not exactly correspond with those for which the yield of nitrogen in the Beans was given; some of the Barley and Clover crops having been taken together where no difference in the produce was observable. Thus, half the plot represented as without manure, had been unmanured from the commencement, that is for nearly 40 years, but the other half received some nitrogen to 1878 inclusive, but had since been entirely unmanured. Again, the results given in the second line relate to the produce of a plot part of which received purely mineral manure, but the other part ammonium-salts or nitrate up to 1878, but none since. The results given in the third line relate, however, to a plot which has not received any nitrogenous manure from the commencement of the experiments with the Beans, but which

was not brought under experiment until 5 years later than the other plots.

Thus, on a plot where a purely mineral manure containing potash, but no nitrogen, had been applied for 27 years, to 1878 inclusive, and no manure since, 347·3 lbs. of nitrogen were gathered per acre, almost wholly by the Leguminous crop—Clover. On a plot on part of which the mineral only, and on part the same mineral manure and ammonium-salts or nitrate had been applied up to 1878, but nothing since, 330·2 lbs. of nitrogen were removed in the crops. Lastly, where, to half of the plot no manure whatever had been applied for nearly 40 years, but to the other half ammonium-salts or nitrate had been applied up to 1878, the yield of nitrogen in the Barley and Clover was 280·9 lbs.

Here, then, in a field where Beans had been grown for many years in succession, and had yielded much less than average crops, and the land had then been left fallow for several years; where the surface-soil had become very poor in total nitrogen; where both surface and sub-soil were very poor in ready-formed nitric acid; and where there was a minimum amount of crop residue near the surface for decomposition and nitrification, there were grown very large crops of clover, containing very large amounts of nitrogen.

Not only was so much nitrogen removed in the crops, but the surface-soils became determinably richer in nitrogen, as the results in Table XIV. (below) show. There are there given, the percentages of nitrogen in the sifted dry surface-soil of the three plots for which the produce and the nitrogen in the Beans have been given. The results relate to samples taken in April 1883, before the sowing of the Barley and Clover, and in November 1885, after the removal of the crops. The first two columns show the percentages of nitrogen, and the other columns the calculated amounts of nitrogen per acre, in the surface-soils, 9 inches deep, at the different dates, and the estimated gain of nitrogen under the influence of the growth of the clover.

TABLE XIV.

Nitrogen, per cent. and per acre, in the surface-soils, before and after the growth of the Barley and Clover.

	Nitrogen in sifted dry soil.				
	Per cent.		Per acre.		
	1883.	1885.	1883.	1885.	1885 + or − 1883.
	Per cent.	Per cent.	lbs.	lbs.	lbs.
1. Without Manure	0·0993	0·1083	2441	2662	+ 221
2. With Mineral Manure containing Potash	0·1087	0·1149	2672	2824	+ 152
3. With Mineral Manure and Nitrogen	0·1163	0·1225	2859	3011	+ 152

Without assuming that the figures represent accurately the amounts of nitrogen accumulated per acre, it cannot be doubted that the

surface-soils had become considerably richer. If, for the sake of illustration, we assume that 300 lbs. of nitrogen were removed per acre in the crops, and that 150 lbs. were accumulated in the surface-soil, we have 450 lbs. of nitrogen to account for, as gathered by the crops within a period of little more than two years.

It is clear that we have in the experimental results themselves no conclusive evidence as to the source of so large an amount of nitrogen. As the surface-soil became determinably richer, it is obvious that it must have been derived either from above or below it—from the atmosphere, or from the sub-soil; and, if from the sub-soil, the question arises—whether it was taken up as nitric acid, as ammonia, or as organic nitrogen? I shall have to adduce evidence bearing on these points further on; but it must be admitted that there is nothing in the experimental results themselves, to show that so large an amount of nitrogen could have been available as nitric acid.

VARIOUS LEGUMINOUS PLANTS GROWN AFTER RED CLOVER.

I have now to adduce another, and even much more striking instance, of successful growth, and of great accumulation of nitrogen, by plants of the Leguminous family, on soil where another plant of the same family had failed, and where the surface-soil had become very poor in nitrogen.

The experiments were made on the plots where it had been attempted to grow Red Clover year after year on the same land; where, in fact, Clover had been sown 12 times in 30 years, and where, in 8 out of the last 10 trials, the plant had died off in the winter and spring succeeding the sowing of the seed; in 4 cases without any crop at all, and in the other 4 yielding very small cuttings.

In 1878, the land was devoted to experiments with various Leguminous plants, differently manured, having regard, however, to the previous manurial history of the plots.

The object was to ascertain whether, among a selection of plants all belonging to the Leguminous family, but of different habits of growth, and especially of different character and range of roots, some could be grown successfully for a longer time, and would yield more produce, containing more nitrogen, as well as other constituents, than others; all being supplied with the same descriptions and quantities of manuring substances, applied to the surface-soil. Further, whether the success in some cases, and the failure in others, would afford additional evidence as to the source of the nitrogen of the Leguminosæ generally, and as to the causes of the failure of Red Clover when grown too frequently on the same land.

Accordingly, 14 different *Leguminosæ* were selected, and sown in 1878. These included 8 species or varieties of *Trifolium*, 2 species of *Medicago*, *Melilotus leucantha*, *Lotus corniculatus*, *Vicia sativa*, and *Lathyrus pratensis*. Of these, 6 of the 8 *Trifoliums* have already failed, and been replaced by other plants; as also have the *Medicago*

lupulina, the *Lotus corniculatus*, and the *Lathyrus pratensis*; the last being replaced in the second year by *Onobrychus sativa*. The plants which have maintained fair, but very varying character of growth, are the *Trifolium repens*, *Vicia sativa*, *Melilotus leucantha*, and *Medicago sativa*; and I propose to give some account of the growth of these plants on this Clover-exhausted soil.

That the surface-soil had become very poor in nitrogen is evident from the fact, that the mean percentage of it in the sifted dry surface-soil of 5 of the Clover plots was, in March 1881, only 0·1058, which is considerably lower than was found in the same field many years before, and lower than has been found in any of the fields at Rothamsted excepting those where crops have been grown for many years on the same land without nitrogenous manure. It is a point of interest, however, that the percentage in the surface-soil is not so low as in immediately adjoining land, which has been under alternate Wheat and Fallow for nearly 30 years without manure.

The real interest of the results depends on the amounts, and on the difference in the amounts, of nitrogen, which the various plants have assimilated over a given area, all growing side by side on the same Red-clover-exhausted land, and with the same mineral manures, without any nitrogen supply.

Accordingly, the upper part of Table XV. (p. 32) shows the estimated average amounts of nitrogen in the Gramineous crop, Wheat, grown in alternation with Fallow, over 27 years to 1877 inclusive, and in the Red-clover, (together with other crops when it failed) over 29 years, also to 1877 inclusive. Then, in the body of the Table are given, the amounts of nitrogen in the Wheat alternated with Fallow, and in the produce of five different Leguminous plants, during the subsequent years, commencing with 1878, and ending with 1888.

Thus, over the preliminary period, the Wheat gave an average annual yield of nitrogen per acre of 17 lbs., and the Clover gave, over much the same period, an average of 32 lbs. of nitrogen.

Against these amounts, the various crops yielded, over the subsequent years, averages as follows:—The Fallow Wheat, over 11 years, 12 lbs.; the Red Clover (Trifolium pratense), over 8 years, 14 lbs.; the White Clover (Trifolium repens), over 11 years, 26 lbs.; the Vetch (Vicia sativa), over 11 years, 77 lbs.; the Bokhara Clover (Melilotus leucantha), 62 lbs.; and the Lucerne (Medicago sativa), over 11 years, 136 lbs.

Or, if we take the average amounts over the years of actual crop only, the amounts were—in the Wheat 22 lbs., in the Red Clover 22 lbs., in the White Clover 47 lbs., in the Vetch 77 lbs., in the Bokhara Clover 68 lbs., and in the Lucerne the enormous amount of 166 lbs., of nitrogen per acre per annum.

Again, if we take the total yields of nitrogen over the experimental periods, we have, in the Wheat 133 lbs., in the Red Clover 112 lbs., in the White Clover 283 lbs., in the Vetch 846 lbs., in the Bokhara Clover 679 lbs., and in the Lucerne 1,492 lbs.; that is, in the Lucerne

about eleven times as much as in the Wheat, and more than thirteen times as much as in the Red Clover. Indeed, this very deeply, and very powerfully rooting plant, yielded, in its above-ground produce alone, 337 lbs. of nitrogen in 1884, 270 lbs. in 1885, 167 lbs. in 1886, 247 lbs. in 1887, and 161 lbs. in 1888.

TABLE XV.

Estimated yield of Nitrogen per acre, in lbs., in Wheat alternated with Fallow, and in various Leguminous Crops, without Nitrogenous Manure.

	Unmanured Fallow Wheat.	Mineral Manures only.				
		Trifolium pratense.	Trifolium repens.	Vicia sativa.	Melilotus leucantha.	Medicago sativa.
PRELIMINARY PERIOD. WHEAT AND FALLOW, 27 yrs., 1851-'77. RED CLOVER, &c., 29 yrs., 1849-'77.						
Average per acre per annum ..	lbs. 17	lbs. 32				
EXPERIMENTAL PERIOD.						
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1878	29	0	0	51	53	0
1879	Fallow	50	82	46	130	0
1880	24	8	0	58	36	28
1881	Fallow	21	8	65	60	28
1882	18	18	74	146	145	111
1883	Fallow	0	0	101	27	143
1884	29	0	0	113	56	337
1885	Fallow	15	97	90	58	270
1886	14	Lupins	16	52	0	167
1887	Fallow	0	6	64	82	247
1888	19	Medicago sativa	0	60	32	161
Total, 11 years, 1878-'88.. ..	133	112*	283	846	679	1492
Average, 11 years, 1878-'88 ..	12	14*	26	77	62	136
Average for years of crop ...	22	22	47	77	68	166

* Eight years only, 1878-'85.

Not only have these large amounts of nitrogen been removed in the above-ground produce, but determinations of nitrogen in the surface-soils of the Vetch plot in 1883, and of the White Clover, the Bokhara Clover, and the Lucerne plots, in 1885, have shown, as in the case of the Clover after the Beans, that the surface-soil has gained rather than lost nitrogen, due to the accumulation of nitrogenous crop-residue. Here again, then, it is obvious, that the original source of the nitrogen of the crops has not been the surface-soil. It must have been derived either from the atmosphere or from the sub-soil.

The next results will throw some light on this point. Thus, having made initiative experiments of the same kind some years previously, in July, 1883, samples of soil were taken to the depth of 12 times 9 inches, or 108 inches in all, on the Wheat fallow plot, on the White Clover plot, and on two of the Vetch plots, for the determination of the

amount of nitrogen existing as nitric acid, at each depth. Table XVI. summarises the results.

TABLE XVI.

Nitrogen as Nitric Acid, per acre, lbs., in soils of some experimental plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted.

Samples collected July 17-26, 1883.

Depths.	Wheat-Fallow Land. Unmanured.	Trifolium repens. Series 1. Plot 4.	Vicia sativa. Series 1. Plot 4.	Vicia sativa. Series 1. Plot 6.	Trifolium repens + or − Wheat Land.	+ or − Trifolium repens.	
						Vicia sativa. Plot 4.	Vicia sativa. Plot 6.
Inches.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1-9	19·85	30·90	12·16	10·22	+ 11·05	— 18·74	— 20·68
10-18	8·05	27·73	4·11	2·72	+ 19·68	— 23·62	— 25·01
19-27	2·47	8·44	1·37	1·08	+ 5·97	— 7·07	— 7·36
28-36	2·70	7·64	1·67	1·52	+ 4·94	— 5·97	— 6·12
37-45	1·62	9·07	4·58	2·51	+ 7·45	— 4·49	— 6·56
46-54	3·57	8·77	6·37	4·42	+ 5·20	— 2·40	— 4·35
55-63	3·84	7·92	7·16	4·52	+ 4·08	— 0·76	— 3·40
64-72	2·28	8·34	5·95	4·92	+ 6·06	— 2·39	— 3·42
73-81	1·48	8·27	4·54	4·81	+ 6·79	— 3·73	— 3·46
82-90	1·76	9·95	5·32	5·14	+ 8·19	— 4·63	— 4·81
91-99	2·94	9·16	5·66	6·40	+ 6·22	— 3·50	— 2·76
100-108	1·84	9·51	5·32	6·46	+ 7·67	— 4·19	— 3·05
			SUMMARY.				
1-27	30·37	67·07	17·64	14·02	+ 36·70	— 49·43	— 53·05
28-54	7·89	25·48	12·62	8·45	+ 17·59	— 12·86	— 17·03
55-81	7·60	24·53	17·65	14·25	+ 16·93	— 6·88	— 10·28
82-108	6·54	28·62	16·30	18·00	+ 22·08	— 12·32	— 10·62
1-54	38·26	92·55	30·26	22·47	+ 54·29	— 62·29	— 70·08
55-108	14·14	53·15	33·95	32·25	+ 39·01	— 19·20	— 20·90
1-108	52·40	145·70	64·21	54·72	+ 93·30	— 81·49	— 90·98

The first point to notice is that, at each depth, from the first to the twelfth, the *Trifolium repens* soil contains much more nitrogen as nitric acid than the Wheat fallow soil; and, as the figures at the bottom of the Table show, whilst to the total depth of 108 inches, or 9 feet, the Wheat fallow soil is estimated to contain per acre only 52·4 lbs. of nitrogen as nitric acid, the *Trifolium repens* soil, that is the Leguminous plant soil, contained to the same depth 145·7 lbs.

Now, independently of the fact that the Leguminous plant plots had received mineral manures, and the Wheat land had not, the characteristic difference in the history of the two plots was, that the one had, from time to time grown a Leguminous crop, and the other had not, and the one which had grown Leguminous crops contained, to the depth of 9 feet, nearly 3 times as much nitrogen as nitric acid as the Gramineous crop soil.

The difference is the greatest near the surface, but it is very considerable down to the lowest depths. In the first three depths,

there is more than twice as much nitrogen as nitric acid in the *Trifolium repens*, as in the Wheat fallow soil; in the second and third 3 depths, there is more than 3 times; and in the fourth 3, more than 4 times as much. Hence it is obvious, that any loss by drainage would be much the greater from the *Trifolium* plot, so that the difference between the two plots was probably greater than the figures show.

In the case of both plots the actual amount of nitrogen as nitric acid is the greatest near the surface, indicating more active nitrification; and the greater amount in the *Trifolium* soil is doubtless due to more nitrogenous crop-residue from the Leguminous than from the Gramineous crop. Indeed, as Table XV. (p. 32) shows, about 74 lbs. of nitrogen had been removed in the *Trifolium repens* crops, and only 18 lbs. in the Wheat, in 1882, and none from either in 1883, the year of soil sampling; and the crop-residue of the *Trifolium repens* would contain much more nitrogen than that of the Wheat. But it is not probable that the excess of nitric acid in the *Trifolium* soil, together with the larger amount lost by drainage, could be entirely due to the nitrification of recent crop-residue. Some found in the lower layers is, however, doubtless due to washing down from the surface. But as, notwithstanding much more nitrogen had been removed in the crops from the Leguminous than from the Gramineous crop land during the preceding 30 years, the surface-soil of the Leguminous plot remained slightly richer in nitrogen, it is obvious that the whole of the nitrogen of the nitric acid could not have had its origin in the surface-soil. If, therefore, it did not come from the atmosphere, it has been derived from the sub-soil.

The indication is, that nitrification is more active under the influence of Leguminous than of Gramineous growth and crop-residue. There would not only be more nitrogenous matter for nitrification, but it would seem that the development of the nitrifying organisms is the more favoured. Part of the result may, therefore, be due to the passage downwards of the organisms, and the nitrification of the organic nitrogen of the sub-soil.

An alternative is, that the soil and the sub-soil may still be the source of the nitrogen, but that the plants may take up, at any rate part, as ammonia, or as organic nitrogen. To this point I shall recur presently.

Comparing the amounts of nitrogen as nitric acid in the *Vicia sativa* soils, with those in the *Trifolium repens* soil, it is to be observed, that whilst from the *Trifolium repens* soil only 164 lbs. of nitrogen had been removed per acre in the crops of the five years to 1882 inclusive, 366 lbs. had been removed in the *Vicia* crops to the same date. Then, whilst none was removed in crops from the *Trifolium* plot in 1883, 101 lbs. were removed in the *Vicia* crops just before soil-sampling. Under these circumstances, one of the *Vicia* soils contains 81·5 lbs., and the other 91 lbs., less nitrogen as nitric acid per acre, than the *Trifolium repens* soil.

Of course we cannot know exactly how much was at the disposal of

the plants at the commencement of growth; but if there had only been as much as in the case of the *Trifolium* plot, it is seen that the deficiency in the *Vicia* soils nearly corresponds with the amount removed in the crop, which was 101 lbs. It may at any rate safely be concluded, that most, if not the whole, of the nitrogen of the *Vicia* crops, had been taken up as nitric acid.

But as the *Vicia* crops had removed much more in the preceding years than the *Trifolium* crops, so also would their crop-residue be greater; and, in fact, much more nitrogen must have been taken up by the plants each year than the figures show; and the larger the crop-residue, the larger would be the amount of nitric acid for each succeeding crop. But the crop of 1883 was also large, and it would leave a correspondingly large nitrogenous crop-residue; leaving, therefore, a large amount of the nitrogen assimilated to be otherwise accounted for than by previous crop-residue.

Lastly in reference to these experiments, it is seen that, at each of the 12 depths, the *Vicia* soils with growth, contained much less nitric acid than the *Trifolium* soil without growth; and the difference is much the greatest in the upper 4 or 5 depths, within which the *Vicia* throws out by far the larger proportion of its feeding roots; but the deficiency is quite distinct below this depth; the supposition being that, under the influence of the growth, water had been brought up from below, and with it nitric acid. In fact, the determinations showed that, down to the depth of 108 inches, the *Vicia* soils contained less water than the *Trifolium* soil, in amount corresponding to between 6 and 7 inches of rain, or to between 600 and 700 tons of water per acre.

Experiments of the same kind were again made in 1885. *Trifolium repens* was again selected as the weak and superficially rooting plant, *Melilotus leucantha* as a deeper and stronger rooting one, and the *Medicago sativa* as a still deeper, and still stronger rooting plant. Samples of soil were taken at the end of July and the beginning of August, from 2 places on each plot, and, in each case, as before, to 12 depths of 9 inches each, or to a total depth of 108 inches, or 9 feet. It will suffice to quote the results for the *Trifolium repens* and the *Medicago sativa* plots. They are given in Table XVII. (p. 36).

It is seen that there was much less nitrogen as nitric acid in the *Trifolium* soil in 1885, after the removal of 97 lbs. in the crops, than in 1883 (see Table XVI., p. 33), when there had been no crop. The deficiency is the greatest in the two upper layers, but it extends to the fifth depth, representing the range of the direct and indirect action of the superficial roots. Below this point there is, however, even more than in 1883; due, doubtless, in part to percolation from above during the two preceding seasons without growth, and possibly in part to percolation of the nitrifying organisms, and the nitrification of the nitrogen of the sub-soil.

Let us now compare the results relating to the *Medicago sativa* with those relating to the *Trifolium repens* soils.

TABLE XVII.

Nitrogen as Nitric Acid, per acre, lbs., in the soils and sub-soils of some experimental plots, without Nitrogenous Manure for more than 30 years.

Hoosfield, Rothamsted.

Samples collected July 29 to August 14, 1885.

Depths.	Series 1. Mineral Manures.		
	Trifolium repens. Plot 5.	Medicago sativa. Plot 5.	Medicago sativa + or — Trifolium repens.
Inches.	lbs.	lbs.	lbs.
1-9	11·50	8·88	— 2·62
10-18	1·38	1·11	— 0·27
19-27	0·90	0·78	— 0·12
28-36	1·86	0·81	— 1·05
37-45	7·08	0·99	— 6·09
46-54	11·31	0·93	— 10·38
55-63	13·14	0·57	— 12·57
64-72	12·63	0·81	— 11·82
73-81	11·19	0·70	— 10·49
82-90	10·70	0·61	— 10·09
91-99	11·08	0·44	— 10·64
100-108	9·96	0·41	— 9·55
Total ..	102·73	17·04	— 85·69
SUMMARY AND CONTROL.			
1-9	11·50	8·88	— 2·62
10-18	1·38	1·11	— 0·27
Mixture of 19-108 inches	88·02	6·97	— 81·05
Total ..	100·90	16·96	— 83·94

The Table of the estimated nitrogen in the produce per acre (p. 32), shows that, whilst from the commencement to 1885 inclusive, the *Trifolium repens* yielded only 261 lbs. of nitrogen in crops, the *Medicago* gave 917 lbs.; and again, whilst in 1885, the year of soil-sampling, the *Trifolium* gave only 97 lbs., the *Medicago* gave 270 lbs. It is further to be observed that, quite accordantly with the usual character of growth of Lucerne in agriculture, with the increasing root-range, and consequently increased command of the stores of the soil and sub-soil, the yield of nitrogen increased from 28 lbs. in the first and second years, to 337 lbs. in the fifth year of growth, declining, however, somewhat afterwards.

Under these circumstances of very large yields of nitrogen in the crops, there is, at every one of the twelve depths, less, and at most very much less, nitrogen as nitric acid remaining in the soil than where so much less had been removed in the *Trifolium repens* crops. The difference is distinct even in the upper layers; but it is very striking in the lower depths. Thus, there is, on the average, not one-twelfth as much nitric-nitrogen in the lower 10 depths of the soil of the deep-rooting and high-nitrogen yielding *Medicago sativa*, as in those of

the shallow-rooting and comparatively low nitrogen yielding *Trifolium repens*. Indeed, the nitric acid is nearly exhausted in the deep-rooting *Medicago sativa* plot; there remaining, to the total depth of 9 feet, only about 17 lbs. of nitric-nitrogen, against more than 100 lbs. to the same depth in the *Trifolium repens* soil. The total deficiency of nitric-nitrogen in the *Medicago* as compared with the *Trifolium repens* soil, is seen to be 85·69 lbs. according to one set of determinations, and 83·94 lbs. according to the other.

As already said, we cannot know what was the stock of nitric-nitrogen in the soil at the commencement of the growth of the season, or the amount formed during the growing period. But, with so much more *Medicago* growth for several previous years, it seems reasonable to assume that there would be much more nitrogenous crop-residue for nitrification than in the case of the *Trifolium repens* plot.

But even supposing, for the sake of illustration, that each year's growth would leave crop-residue yielding an amount of nitrogen as nitric acid for the next crop, or succeeding crops, approximately equal to the amount which had been removed in the crop, the increasing amounts of nitrogen yielded in the crops from year to year could not be so accounted for; and there would remain the amount of nitrogen in the crop-residue itself, still to be provided in addition. In fact, assuming the proportion of nitrogen in the crop-residue to that in the removed crop to be as supposed in the above illustration, nearly 700 lbs. of nitrogen would have been required for the *Medicago* crop and crop-residue of 1884; or, if we assume the nitrogen in the residue to be only half that in the crop, about 500 lbs. would have been required. Doubtless, however, some of the nitrogenous crop-residue would accumulate from year to year.

The results can leave no doubt that the *Trifolium repens*, and the *Medicago sativa*, have each taken up much nitrogen from nitric acid within the soil, and that, in fact, nitric acid is an important source of the nitrogen of the Leguminosæ. Indeed, existing direct experimental evidence relating to nitric acid, carries us quantitatively further than any other line of explanation. But, it is obviously quite inadequate to account for the facts of growth, either in the case of the *Medicago sativa* after the Clover, or in that of the Clover after the Beans.

It is obvious that, if nitric acid were the source of the whole, there must have been a great deal formed by the nitrification of the nitrogen of the sub-soil. A difficulty in the way of the assumption that nitric acid is the exclusive, or even the main source of the nitrogen of the Leguminosæ is, that the direct application of nitrates as manure, has comparatively little effect on the growth of such plants. In the case of the direct application of nitrates, however, the nitric acid will percolate chiefly as sodium or calcium nitrate, unaccompanied by the other necessary mineral constituents in an available form; whereas, in the case of nitric acid being formed by direct action on the sub-soil, it is probable that it will be associated with other constituents, liberated, and so rendered available, at the same time.

EXPERIMENTS ON THE NITRIFICATION OF SOILS AND SUB-SOILS.

It was obviously important to determine by direct experiment, whether the nitrogen existing in a comparatively insoluble condition in raw clay sub-soil, was susceptible of nitrification.

It had already been found at Rothamsted, that the sub-soils of rich Prairie-land were subject to nitrification; but considering the conditions of the collection and transmission of the samples in question, it was considered possible that comparatively recent organic matter from the surface-soil might not have been entirely excluded. Accordingly, experiments were made with some of the Rothamsted raw clay sub-soils.

The percentages of total nitrogen in the samples was determined. The nitrogen as nitric acid was determined in the dry sifted soil, both before and after exposure for some months under suitable conditions as to temperature and moisture. After the first extraction, the soils were seeded with from 0·1 to 0·2 gram of rich garden-soil, assumed to contain nitrifying organisms, and by 0·2 gram more after some subsequent extractions. Further, after 3 or 4 extractions, which had of course removed the soluble mineral matters, a mineral mixture was added.

The results have been given and discussed in detail elsewhere, and their general indication may be stated as follows:—Results obtained with raw, and mostly clay, sub-soils, which contain not more than 6 or 8 parts of carbon to 1 of nitrogen, confirm those previously obtained with Prairie sub-soils containing a much higher proportion of carbon, in showing that their nitrogen is susceptible of nitrification, provided the organisms, and other essential conditions, are not wanting. The results also consistently showed, that there is more active nitrification in Leguminous than in Gramineous crop sub-soils. This, it must be supposed, is partly due to more active development, and greater distribution, of the organisms themselves, under the influence of the Leguminous growth, with its excretions and residue, and partly to the greater actual amount of such easily changeable matters, with the greater amount of nitrogenous crop-residue.

The results are also confirmed by those of experiments made in the Rothamsted Laboratory by Mr. Warington, on quite distinct lines. His plan was to introduce a portion of the sub-soil into a sterilised nitrogenous liquid, and to determine whether nitrification took place; the result being taken to show whether or not the organisms were present in the sub-soil. From his first results he concluded that in our clay soils the nitrifying organism is not uniformly distributed much below 9 inches from the surface; that it is sparsely distributed down to 18 inches, or possibly somewhat further; but that at depths from 2 feet to 8 feet, there was no trustworthy evidence to show that the clay contained the nitrifying organism.

Subsequently, he experimented with a greater variety of sub-soils, and with some taken in the immediate neighbourhood of lucerne roots, and gypsum was added to the sterilized liquids.

Among the 69 experiments made in this new series, there was no failure to produce nitrification by samples down to 2 feet; there was only one failure out of 11 trials down to 3 feet; but below 3 feet, the failures were more numerous. Taken at 6 feet, about half the samples induced nitrification. The order of priority of nitrification diminished from the upper to the lower depths; indicating more sparse occurrence, or more feeble power of development and action. There was, moreover, notably more active nitrification with the Leguminous than with the Gramineous crop sub-soils.

It is, then, established, that the nitrogenous matters of raw clay sub-soils are susceptible of nitrification, if the organisms, with the other necessary conditions, are present. It is further indicated, not only that the action is more marked under the influence of Leguminous than of Gramineous growth and crop-residue, but that the organisms become distributed to a considerable depth, even in raw clay sub-soils, especially where deep rooted and free growing Leguminosæ have developed.

The next question is, how far, in a quantitative sense, do the results aid us in explaining the source of the large amounts of nitrogen taken up by some Leguminous crops?

In the case of three Leguminous crop sub-soils there was, over the total period, only about 1 part of nitrogen nitrified per million of soil; and as the sub-soil, to the depth experimented on, would weigh about 30 million lbs. per acre, the amount of nitrification supposed would represent only about 30 lbs. of nitric-nitrogen per acre. Obviously the conditions of nitrification in which the samples are exposed in the Laboratory are very different from those of the sub-soil *in situ*. Thus, whilst in the case of the samples in the Laboratory, the conditions as to temperature, and, perhaps of aëration, would be the more favourable, the successive extractions by water under pressure, would be liable to remove, not only the mineral matters essential for the development of the organisms, and for the production of nitric acid, but the organisms themselves; whereas, in the case of the natural sub-soil, the tendency would be to multiplication.

Compared with the small amount of nitrification of the nitrogen of the raw clay sub-soils shown in the foregoing experiments, some results obtained by Mr. Warington, in experiments in which he mixed raw clay sub-soil with an equal weight of coarsely powdered flint, seeded the mixture with rich garden-soil, moistened it, and placed it in a vessel allowing of free access of washed air, show, in one case 12·9 and in the other 11·8 parts of nitrogen nitrified per million of sub-soil; and, when mineral plant food was added to the subsoils, the amounts of nitrogen nitrified were raised to 21·4, and 14·2, parts, per million. It is obvious, therefore, that there would be little difficulty in accounting even for the large amounts of nitrogen taken up by the *Medicago sativa* were it established, which it certainly is not, that coincidently with the deep-rooted growth, both the nitrifying organisms, and air, were abundantly present in the sub-soil.

Indeed, the greatest difficulty in the way of the supposition that much nitrogen is available to plants by the nitrification of the nitrogen of the sub-soil, is the want of sufficient aëration. Independently of the greater or less porosity of the sub-soil itself, and of the channels formed by worms, it is obvious that, wherever the roots go, water and its contents can follow; and that, with deep-rooted plants, and free growth, there will be active movement of water, and there must be of air also, in the lower layers of the soil. In experiments made in 1882, there remained in the *Melilotus* soil, less water than in the *Trifolium repens* soil where there had been less growth, in amount corresponding, down to a depth of 54 inches, to a loss of 540 tons per acre, or nearly 5½ inches of rain; and, as already stated, in 1883, the *Vicia sativa* soils showed, down to 108 inches, less water than the *Trifolium repens* soil, in amount corresponding to between 600 and 700 tons per acre, or to between 6 and 7 inches of rain. Obviously too, the still deeper rooting, and still freer growing, *Medicago sativa*, would remove still more water.

Although much experiment, and much calculation, have been devoted by several investigators to the estimation of the degree of aëration of soils and sub-soils of different character, the data at command do not justify any very definite conclusions on the subject. The results seem to indicate a probable range of aëration from about 30 to over 50 per cent. of the volume of the soil. But these estimates do not take into account the varying amounts of water in the soil or sub-soil. In the case of the sub-soils above referred to, each layer of 9 inches in depth retained from about 2 to nearly 4 inches of water, the amount varying very much, according to the nature of the sub-soil, and especially according to the amount of growth, and the consequent withdrawal of water from below, and its evaporation, chiefly through the plant, but partly also from the surface soil. The amount must, obviously, also vary very much according to the character of the season.

It may be stated that, supposing the sub-soil contained at one time, air equal to one third of its volume, this would not suffice for the nitrification of as much nitrogen as was taken up each year, for several years in succession, by the *Medicago sativa*; or during the two years in the case of the Red-clover on the Bean-exhausted land. But the nitrogen is not taken up all at once, though much of it will be within a few months of the year, during which period there would be the most active withdrawal of water from below, and evolution by the plant, and evaporation by the surface-soil. The replacement of this sub-soil water by an equal volume of air would, however, still not suffice. The question obviously arises—how far, or how rapidly, the used up oxygen will be replaced, and on this point there is very little experimental evidence to aid us.

Thus, then, the evidence is clear, that the nitrogen of raw clay sub-soils, which constitutes an enormous store of already combined nitrogen, is susceptible of nitrification, provided the organisms are

present, and the supply of oxygen is sufficient; but the data at command do not justify the conclusion that these conditions would be adequately available in such cases as those of the very large accumulations of nitrogen by the Red-clover grown after the Beans, and of the increasing, and very large accumulations, by the *Medicago sativa*, for a number of years in succession.

The alternatives are—either that the plant may take up nitrogen from the sub-soil in some other way, as ammonia, or as organic nitrogen; or that the free nitrogen of the atmosphere is in some way brought under contribution.

CAN ROOTS, BY VIRTUE OF THEIR ACID SAP, ATTACK, AND RENDER AVAILABLE, THE OTHERWISE INSOLUBLE NITROGEN OF THE SUB-SOIL?

In reference to the first of the above alternatives, the question suggested itself whether roots, by virtue of their acid sap, may not, either directly take up, or at any rate attack and liberate for further change, the otherwise insoluble organic nitrogen of the sub-soil?

Accordingly, in the autumn of 1885, specimens of the deep, strong, fleshy root of the *Medicago sativa* were collected and examined; when it was found that the sap was very strongly acid. The degree of acidity of the juice was determined; and attempts were made so to free the extract from nitrogenous bodies as to render it available for determining whether or not it would attack and take up the nitrogen of the raw clay sub-soil. Hitherto, however, these attempts have been unsuccessful. But it may be of interest to state, as indicating the extent of the command of the sub-soil which such plants acquire, that, of the 3 plants collected, the roots of one had four branches, respectively, 6 feet 4½ inches, 5 feet 10½ inches, 3 feet 6½ inches, and 2 feet 9½ inches, in length; the second had two branches—4 feet 10, and 2 feet 2 inches, long; and the third two branches—3 feet 9, and 1 foot 9 inches, in length.

ACTION OF DILUTE ORGANIC ACID SOLUTIONS ON THE NITROGEN OF SOILS AND SUB-SOILS.

Experiments were next made to determine the action on soils and sub-soils, of various organic acids, in solutions of a degree of acidity either approximately the same as that of the *Medicago sativa* root-juice, or having a known relation to it. These experiments and their results have been fully detailed elsewhere, and only their general indications can be referred to here.

Obviously, however, the conditions of experiments in which an acid solution is agitated with a quantity of soil in a bottle, are not comparable with those of the action of living roots on the soil. The root action would necessarily affect only a very small proportion of the total soil. But the results showed, that the more nitrogen was taken up the greater the acidity of the solution, and the question arises,

whether the root action would not effect more resolution on the surfaces actually attacked. Indeed, this must necessarily be the case, if such an action is really quantitatively an important source of the nitrogen taken up by deep and strong rooting plants, with strongly acid-sap. In illustration of this necessity it may be stated that, even if as much as 20 parts of nitrogen were taken up per million of soil, as was the case in some of the experiments, this would only represent 600 lbs. of nitrogen per acre to the depth examined, namely, 108 inches.

Upon the whole, the experiments on the action of weak organic acid solutions on raw clay sub-soil, did not give results from which any very definite conclusions can be drawn, as to the probability that the action of roots on the soil, by virtue of their acid sap, is quantitatively an important source of the nitrogen of plants having an extended development of roots, of which the sap is strongly acid.

That roots do attack certain mineral substances by virtue of their acid-sap, was established by Sachs. It was to carbonic acid that he attributed the action ; but there seems no reason to suppose that other acids in the root-sap may not exert a similar action. The published results of Sachs and others have, however, reference only to the taking up of mineral substances from the soil by virtue of such an action ; and the possibility or probability that the nitrogen of the soil or sub-soil is so taken up, has, I believe, not been considered.

As bearing on the point, it may be stated that Dr. G. Loges and M.M. Berthelot and André, by extracting rich soils by strong hydrochloric acid, have found that soluble amides are obtained. Supposing the acid root-sap so to act on the insoluble organic nitrogen of the soil, and especially of the sub-soil, the question would still remain—whether the amide rendered soluble is taken up by the plant as such, as seems to be probable in the case of the fungi, or whether it undergoes further change—into ammonia or nitric acid—before serving as food for the plants ?

The first point to consider is, then, whether chlorophyllous plants can take up amide-bodies and assimilate their nitrogen ?

Many vegetation experiments have been made to determine this point. In the case of experiments in which soil was used as a matrix, it seemed probable that the amide-body suffered change before becoming available as a source of nitrogen. In the case of some water-culture experiments, however, it was concluded that the amide-body was taken up by the plant as such, and contributed directly as a source of nitrogen to it. It would seem not improbable, therefore, that they might take up directly, and utilize, amide-bodies rendered soluble within the soil by the action of their acid root-sap.

As a portion of the nitrogen of the soil, when acted upon by acids, is liberated as ammonia, it is a question whether this will be either wholly, or partially, nitrified, before being taken up by the plant. Obviously, too, if the portion brought into the condition of soluble amide, be not taken up as such, it also will be subject to further change ; perhaps first into ammonia, and then into nitric acid. But, on such a supposition,

we should obviously be again met with the difficulties in the way of assuming that the conditions within the sub-soil would be adequate for so much nitrification.

It will be seen, therefore, that although significant indications have been obtained, both as to the importance of nitric acid as a source of the nitrogen of the Leguminosæ, and as to the action of acids in rendering soluble the otherwise insoluble nitrogenous compounds of soils and sub-soils, yet on neither of these points is the evidence at present available, adequate to account satisfactorily for the facts of growth.

It will be of interest, briefly to refer to some evidence relating to another mode in which green-leaved plants may acquire nitrogen from the stores already existing in the combined state, but in an insoluble condition, in the soil and sub-soil.

Thus, Professor Frank has observed that the feeding roots of certain trees are covered with a fungus, the threads of which force themselves between the epidermal cells into the root itself, investing the cell, but not penetrating the fibro-vascular tissue. In such cases the root itself has no hairs; but there are similar bodies external to the fungus-mantle, which are prolonged into threads among the particles of soil. The fungus-mantle dies off on the older portions of the root, and its extension is confined to the younger parts, those which are active in the acquirement of nutriment.

Frank considers that the conditions are those of true symbiosis; and that the chlorophyllous tree acquires the carbon, and the fungus the water and the mineral matters, that is the soil-nutriment. He did not refer to nitrogen, but there seems no reason to suppose that the fungus could not, as do the fungi in the case of fairy rings for example, avail itself of the organic nitrogen of the soil.

Here, then, is a mode of accumulation of soil-nutriment by some green leaved plants, which so far allies them very closely to fungi themselves. Indeed, it is by an action on the soil which characterises *non*-chlorophyllous plants, and by virtue of which they are enabled to take up nutriment not available to most green-leaved plants, that the chlorophyllous plant itself acquires its soil supplies of nutriment. It can readily be supposed that, under such circumstances, the tree may acquire not only water and mineral matter, but both organic carbon, and organic nitrogen, from the soil. In reference to this point it may be stated that, from the evidence so far at command, it was concluded that the action is the most marked in the surface layers of the soil rich in humus.

So far as this is the case, it is obvious that such an action of fungi on the soil does not aid us in the explanation of the acquirement of nitrogen from raw clay sub-soil, by the deep and strong rooted Leguminosæ.

Further, it is distinctly stated, that the fungus development in question has not been observed on the roots of any herbaceous plants. It is, nevertheless, a point of interest, should it be established, that by

special means, in special cases, the organic nitrogen of the soil may contribute to the supply of nitrogen to chlorophyllous plants.

I have now considered in some detail the sources of already combined nitrogen available to our crops; and the evidence points to the conclusion that, independently of the small amount of combined nitrogen annually coming from the atmosphere in rain, and the minor aqueous deposits, the source of the nitrogen, at any rate of most of our crops, is the stores already existing within the soil and sub-soil, or those provided by manure. It has further been seen that the combined nitrogen is largely taken up as nitric acid, or rather as nitrates. But it is nevertheless obvious, that we have yet to seek for an explanation of the source of the whole of the nitrogen of the Leguminosæ in some cases.

We are brought to enquire, therefore, what is the evidence relating to the question of *the fixation of free nitrogen*, by the plant, by the soil, or otherwise?

EVIDENCE AS TO THE FIXATION OF FREE NITROGEN.

Even nearly a century ago, it was a matter of discussion whether plants took up, or evolved, free nitrogen; and it is just about half a century, since Boussingault commenced a series of vegetation experiments to determine whether plants do assimilate the free nitrogen of the atmosphere. From the results then and subsequently obtained, he concluded that they did not; and results obtained at Rothamsted nearly 30 years ago confirmed those of Boussingault. But others came to an opposite conclusion; and a somewhat active controversy was maintained on the subject for some time. Eventually it seemed to be pretty generally admitted, that plants did not directly assimilate the free nitrogen of the air. During the last few years, however, the discussion has assumed a somewhat different aspect.

The question still is, whether the free nitrogen of the air is an important source of the nitrogen of vegetation; but whilst few now adhere to the view that chlorophyllous plants directly assimilate free nitrogen; it is nevertheless assumed to be brought under contribution in various ways—coming into combination within the soil, under the influence of electricity, or of micro-organisms, or of other low forms, and so indirectly serving as an important source of the nitrogen of plants of a higher order.

Several of the investigations in the lines here indicated, seem to have been instigated by the assumption, that natural compensation must be found, for the losses of combined nitrogen which the soil sustains by the removal of crops; and for the losses which result from the liberation of nitrogen from its combinations, under various circumstances.

It was about 1876, that M. Berthelot called in question the legitimacy of the conclusion that plants do not assimilate the free

nitrogen of the air, when drawn from the results of experiments in which the plants were so enclosed as to exclude the possibility of electrical action. More recently, he has objected to experiments so conducted with sterilised materials, on the ground that, under such conditions, the presence, development, and action, of micro-organisms, are excluded.

There is, however, I believe, nothing in the recent results, either of Berthelot or of others, which can be held to invalidate the conclusion, drawn from the results of Boussingault, and from those obtained at Rothamsted about 30 years ago, that the higher plants do not fix the free nitrogen of the atmosphere, under the conditions then adopted, which, it is admitted, were such as to exclude, both electrical action, and the influence of micro-organisms.

I propose now to give a brief account of recently published results and conclusions from experiments for the most part made under such conditions as not to exclude the possibility of the influence of electricity, or of micro-organisms. The first to notice are those of M. Berthelot himself.

M. Berthelot first showed that free nitrogen was fixed by various organic compounds, under the influence of the silent electric discharge, at the ordinary temperature; and he suggested that such actions probably take place in the air during storms, and when the atmosphere is charged with electricity, organic matters absorbing nitrogen and oxygen. He also experimented with currents of much weaker tension, more comparable with those incessantly occurring in the air, and in all cases he found that nitrogen was fixed by the organic substance. The gains were in amount such as would explain the source of the nitrogen which he considers crops must derive from the atmosphere.

Subsequently, he found that free nitrogen was brought into combination by argillaceous soils, when exposed in their natural condition, but not when they were sterilised. He also found gain when the natural soils were enclosed. He considered the results showed that there was gain of nitrogen quite independently of any absorption of combined nitrogen; in fact that there was fixation of free nitrogen due to living organisms. He further considered that such gains, not only serve as compensation for exhaustion by cropping, &c., but explain how originally sterile argillaceous soils eventually become vegetable moulds.

He also made experiments on the fixation of free nitrogen by vegetable earth supporting vegetation; and he found that there was a gain about equally divided between the soil and the plant, the latter having taken it up from the soil, which he considers is the true source of gain.

The results obtained under the influence of the silent discharge in bringing free nitrogen into combination with certain vegetable principles, of course owed their special interest to the inference that thus free nitrogen might be brought into combination within the soil, or within the plant; but M. Berthelot subsequently considered it doubtful

whether the higher plants do bring free nitrogen into combination at all. Quite recently, however, he has made new experiments, from which he concludes that nitrogen is fixed under the influence of electricity, both in the soil with its microbes, but without higher vegetation, and in soil with higher vegetation.

Obviously if there are organic compounds within the soil which have the power of bringing free nitrogen into combination under the influence of electricity, the soil may be the source, and yet the agent may be the feeble electric current. But, so far as it is assumed that free nitrogen is brought into combination in the atmosphere itself, the resulting compounds will be found in the air, and in the aqueous depositions from it; and the limit of the amount of combined nitrogen so available over a given area, in Europe at any rate, is pretty well known.

M. Dehérain sought to determine the actual losses or gains in the field, under the influence of different manures, of different crops, and of different modes of cultivation. Experiments were made with various crops, each of which was grown without manure, and with three different descriptions of manure, applied for a series of years, and then the crop was grown without manure for some years more.

The nitrogen was determined in the soil, before the commencement of the experiments in 1875; in 1878 after three years of manuring and cropping; in 1881 after four years' cropping without further manuring; and in the case of sainfoin followed by mixed grasses, in 1885 also. Lastly, the nitrogen in the crops was only estimated. From these data, the losses or gains of nitrogen by the soil, during the different periods, under the influence of the different manures and crops, were calculated.

With regard to the actual amounts of loss or gain of nitrogen found in M. Dehérain's experiments, the losses especially are extremely large, indeed they were far in excess of anything that has come within our own knowledge and experience, and they were in amount such as reflection must show cannot possibly occur in actual practice.

The question arises—how are such results to be explained? I think there can be little doubt that in the method of taking the samples of soil for analysis, an explanation is to be found; and I have the less hesitation in suggesting this, since we fully admit, that our own early results, obtained under somewhat similar conditions, are quite inapplicable for anything like accurate estimates of nitrogen per acre.

In fact, it may be concluded that, certainly the estimated losses by the surface-soils, and probably also the estimated gains, are higher than can possibly happen in practice; and that the results are due to the samples of soil not being taken in such a way, as to ensure strictly comparable estimates at the different periods. At the same time, there can be no doubt that there would be losses beyond those due to the removal of the crops, under the conditions in which losses were found; that is when the land was under arable culture. Nor can there be any doubt that there would be gains in the surface-soil, when the land was

laid down in sainfoin and mixed grasses; and M. Dehérain points out the practical significance of such facts.

M. Dehérain concluded that the loss of nitrogen by arable soil, that is by soil that is mechanically worked, is due to the slow combustion of the nitrogenous organic matter of the soil; the nitrogen being either evolved as free nitrogen, or oxidated into nitric acid and carried down into the sub-soil, or into the drains. As to the gain by the surface-soil, he considers, as is doubtless the case, that part is due to the action of deep-rooted plants, in taking up the nitric acid accumulated in the lower layers, and leaving a nitrogenous residue near the surface; and that as to the gains not so to be accounted for, it is not yet settled whether they are due to the ammonia of the atmosphere, as supposed by M. Schlœsing, or to free nitrogen, as supposed by M. Berthelot.

It may be remarked, that, if the losses in ordinary agriculture were in amount anything like those which M. Dehérain's figures show, even such large gains as are also indicated, would be far from sufficient to compensate them. It would indeed be necessary to seek for other sources of restoration, if our arable surface-soils are not to lose their nitrogen much faster than the evidence at command leads us to suppose is the case in actual practice. That they do, however, slowly suffer reduction in their stock of nitrogen, when there is no restoration from without, there can be no doubt. In other words, in actual practice without restoration from external sources, the losses are not fully compensated.

In conclusion in regard to M. Dehérain's experiments, I may add that he has quite recently reiterated his results and conclusions; but he does not say anything that appears to us to obviate our objections to his quantitative estimates.

M. Joulie made numerous vegetation experiments in which the soils and the plants were, with certain precautions, exposed to the free air, and in which known amounts of combined nitrogen were supplied. He found very variable, but in some cases very large, gains of nitrogen. He considered that the variations of result were largely due to the varying conditions as to mineral-supply in the different experiments.

M. Joulie concluded that microbes probably play an important part in the fixation of nitrogen. He did not think that his results were favourable to the supposition that the plants themselves effected the fixation. For the present he limits himself to the establishment of the great fact of the fixation of the free nitrogen of the atmosphere, leaving to the future the exact explanation.

It is to be observed that the large gains shown were chiefly with a polygonous plant, Buckwheat, and not with plants of the Leguminous family, which are reputed to be "nitrogen collectors."

To show the practical importance of the fixation of free nitrogen, M. Joulie calculates what would be the gain per hectare according to some of his results. It may be confidently affirmed, however, that such gains as he so estimates, do not take place, either with or without vegetation, in ordinary soils, in ordinary practice.

Dr. B. E. Dietzell made vegetation experiments, in which plants were watered with distilled water, the drainage was returned to the soils, and the pots and their contents were exposed to free air, but protected by a linen roof. A rich garden soil, containing 0·415 per cent. of nitrogen, was used, several different conditions as to manuring were adopted, and Peas and Clover were the subjects of experiment. Thus, the plants were of the Leguminous family; but notwithstanding this, there was, in no case, a gain of nitrogen. In one there was neither gain nor loss, and in all the others there was a loss, in some cases amounting to 15 per cent. of the total nitrogen involved.

That there should be loss with a soil containing 0·415 per cent. of nitrogen, that is about three times as much as most ordinary arable soils, is not at all surprising; and it is seen that, neither from the combined nitrogen of the atmosphere, or that due to other accidental sources, nor from free nitrogen, either directly or indirectly, did these reputed "nitrogen collectors" gain nitrogen to compensate the losses from the rich soil.

Professor Frank also made vegetation experiments in free air. His soil was a humus-sand, containing only 0·0957 per cent. of nitrogen; distilled water was used for watering, and the vessels were deep and narrow cylinders, without any arrangement at the bottom for drainage, or for aëration. In three experiments without a plant, in one with two Lupins, and in one with one Lupin and Incarnate Clover together, there was a loss of nitrogen; whilst in one with three Lupins, and in one with one Lupin, there was a gain. Frank considered it probable that where a loss was indicated with vegetation, there had nevertheless been a gain, but not enough to compensate the loss.

In another experiment, with a soil about 12 times as rich in nitrogen, and many times richer than ordinary arable soils, he found a loss, due mainly to evolution of free nitrogen; and, referring to this result, he says that, if such losses take place in ordinary agriculture, there must be natural compensation.

In the experiments in the deep and narrow vessels, without drainage, and without plants to cause evaporation, movement, and aëration, loss by evolution of free nitrogen is only what would be expected. Such loss would also be expected in the two cases of loss with growth, in both of which there was admittedly decomposing organic matter. It was also to be expected in the very rich soil. But it is doubtful whether, in the two cases of gain with growth, and therefore movement within the soil, and aëration of it, there would be any loss. In none of the experiments with loss, however, were the conditions comparable with those of ordinary soils, under ordinary treatment; and the losses found cannot be taken as any indication of what takes place in ordinary practice. It is probable that, in such practice, the loss by evolution of free nitrogen is much less than is generally assumed in discussions of this subject. Doubtless there is, however, frequently considerable loss by the drainage of nitrates.

Frank considers that, independently of direct evidence against the

supposition that the gains were due to the absorption of combined nitrogen from the atmosphere, an objection to such a view is, that it would not explain the circulation of nitrogen in nature; and his main conclusion is, that there are two actions going on within the soil, one liberating nitrogen, and the other bringing it into combination, the latter favoured by vegetation.

Upon the whole, then, it would seem, that the losses found by Frank may be explained by the special conditions of the experiments themselves; whilst the gains, if not to be accounted for by sources of error incidental to experiments made in free air, can only be explained by fixation in some way.

The most remarkable of the results indicating the fixation of free nitrogen are those of Professor Hellriegel and Dr. Wilfarth. Hellriegel found that whilst plants of the Gramineous, the Chenopodiaceous, the Polygonous, and the Cruciferous families, required combined nitrogen to be supplied within the soil, Papilionaceous plants did not depend on such soil-supplies.

Peas, sown in washed sand with nutritive solutions free from nitrogen, generally failed, but occasionally grew luxuriantly; and root-nodules were always developed coincidently with luxuriance, but not without it. But when to the non-nitrogenous sandy matrix, a few c.c. of the watery extract of a rich soil were added, the luxuriance was always marked, as also was the development of the root-nodules. Lupins, however, failed when treated in the same way, but succeeded when the soil was seeded by a watery extract of a sandy soil where Lupins were growing well, and root-nodules were then abundantly produced.

The amounts of produce recorded seemed to leave no doubt that they contained much more nitrogen than was supplied in the seed; whilst the amount added in the soil-extract was quite immaterial. The negative result with Gramineæ, with Peas under sterilised conditions, or in sand not seeded with rich soil-extract, and with Lupins in sand not seeded, or seeded with the rich soil-extract, and, on the other hand, the positive result with Peas in the seeded sand, and with Lupins when the sand was seeded with an extract from a suitable soil, seemed to exclude the supposition of any other source of gain than the fixation of free nitrogen under the influence of micro-organisms; and Hellriegel was disposed to connect the action with the root-nodules and their contents.

Wilfarth gave the results of a subsequent season's experiments, which fully confirmed those recorded by Hellriegel, both as to the negative result with other plants, and to the positive result with Papilionaceæ. Peas grew luxuriantly when the nitrogen-free soil was seeded with the watery extract from any cultivated soil, but Serradella and Lupins, only when seeded with an extract from soil where these plants were growing.

In four experiments with Lupins, nearly 50 times as much dry substance was produced, and nearly 100 times as much nitrogen was assimilated, with, as without, seeding with the soil-extract!

Wilfarth concluded that the Papilionaceæ can derive the whole of their nitrogen from the air, but that it is doubtful whether the root-nodules are connected with the fixation, though the results point to the agency of bacteria in some way.

In reference to these results, whilst it can hardly be said that there is an unsolved problem in regard to the source of the nitrogen of our *non*-Leguminous crops, it must be admitted that, in spite of all the investigations and discussions of the last 50 years, the source of the whole of the nitrogen of our Leguminous crops has not been satisfactorily explained by results obtained on the lines of inquiry until recently adopted. Evidence obtained on new lines should, therefore, receive careful consideration; and there can be no doubt that, in recent years, cumulative evidence has been adduced, indicating that Chlorophyllous plants may avail themselves of nitrogen brought into combination under the influence of lower organisms; the development and action of which would seem in some cases to be a coincident of the growth of the higher plants to be benefited. But such a conclusion is of such fundamental importance, that it seemed desirable it should be confirmed by others. To some results obtained at Rothamsted in this direction, I shall refer further on.

So long ago as 1853, Professor Emil von Wolff obtained 6 times as much dry produce of Clover, grown in an ignited rich meadow soil, as in the same soil in its natural state. Thus, the increased growth, and the increased assimilation of nitrogen, took place in a soil not only nitrogen-free, but sterilised; so that, unless micro-organisms were acquired during growth, the supposition of their influence in fixing free nitrogen would be excluded.

Much more recently, Wolff has made numerous experiments, with Oats, Potatoes, and various Papilionaceæ, in river-sand; in some cases unwashed, and in some washed; in some without manure, in some with purely mineral manure, and in some with nitrate in addition. Accordantly with common experience, there was little increase in the Oats or Potatoes with mineral, but much with nitrogenous manure; and, on the other hand, with the Papilionaceæ there was very marked increase with the mineral manure, and but little more by adding nitrate. In the experiments with Lupins, Beans, and Clover, in unwashed sand, the results indicated gain of nitrogen, beyond that probably due to the nitrogenous impurity in the sand; but with sand-Peas, grown in washed sand, which was assumed to be nitrogen-free, the gains from some external source were unmistakable.

As to the explanation, Wolff does not suppose that free nitrogen is fixed by the plants themselves; nor does he favour the view that it was fixed by the agency of micro-organisms. The plants may take up combined nitrogen from the air by their leaves; but he thinks it more probable that combined nitrogen is absorbed from the air by the soil, and that free nitrogen is fixed within the soil under the influence of porous and alkaline bodies. He admits that it is not explained why Cereals do not benefit by these actions as well as Papilionaceæ; and he

suggests whether the greater evaporation from the leaves of the latter causes greater aëration of the soil.

Here, then, the gain of nitrogen by the Leguminosæ is explained in a very different manner from that assumed by other recent experimenters. It seems, however, that the undoubted fact, that the Gramineæ, and other non-Papilionaceous crops, do not benefit by the actions supposed, excludes the supposition that Wolff's results with Papilionaceæ are to be so explained. It is true that, neither in the growth of the Clover in ignited soil, nor in that of the sand-Peas in the washed sand, were the conditions such as would seem favourable for the presence, development, and agency of micro-organisms. But if, in the experiments in free air, there was no accidental source of combined nitrogen, it would seem that the influence of micro-organisms is at least as probable as that of the actions which Wolff supposes.

Professor Atwater made numerous experiments, both on the germination, and on the growth, of Peas. In eleven out of thirteen experiments on germination, more or less loss of nitrogen was observed. In all but one out of fifteen experiments on vegetation, there was a gain of nitrogen, which was very variable in amount, and sometimes very large. As a general conclusion, he states that, in some of the experiments half or more of the total nitrogen of the plants was acquired from the air.

He considers that germination without loss of nitrogen is the normal process; that loss, whether during germination or growth, is due to decay, and therefore only accessory. Nevertheless, he goes into calculations of some of his own results, showing, by the side of the actual gains, the greater gains supposing there had been a loss of 15 per cent. of nitrogen, and the still greater gains if there had been a loss of 45 per cent., as in an experiment by Boussingault under special conditions. Further, he says that whilst actually observed gains are proof of the acquisition of nitrogen, the failure to show gain only proves non-fixation, if it be proved that there was no liberation. He suggests that the negative results obtained by Boussingault and at Rothamsted, may be accounted for by liberation; though at the same time he recognises that the conditions of the experiments excluded the action of either electricity or microbes. It may be remarked that, in the experiments both of Boussingault and at Rothamsted, any cases of decay were carefully observed, and the losses found explained accordingly; and it may be confidently asserted that the conclusions drawn were not vitiated by any such loss.

Atwater concludes that his results do not settle whether the nitrogen gained was acquired as free or combined nitrogen, by the foliage, or by the soil. He considers, however, that, in his experiments, the conditions were not favourable for the action either of electricity or of micro-organisms; and he favours the assumption that the plants themselves were the agents. Lastly, he considers the fact of the acquisition of free nitrogen in some way to be well established; and that thus facts of vegetable production are explained, which

otherwise remain unexplained. To this, and other points involved, I shall refer again presently.

Lastly, I have to summarise those of the results and conclusions of Boussingault, which bear upon the present aspect of the question of the sources of the nitrogen of vegetation. In his earlier experiments, as in those at Rothamsted, sterilised materials had been used as soils; but in 1858 he commenced a series in which more or less of a rich garden-soil was mixed with sand and quartz. In some cases the plants were grown in free air, and in others in closed vessels with confined air. In several cases there was more or less gain of nitrogen; but the greatest gain was in an experiment with a Lupin grown in a closed vessel. Boussingault points out that it was the soil and not the plant that had fixed the nitrogen. The result was so marked that he repeated the experiment in 1859, when he obtained almost identically the same amount of gain as in 1858. He also put 120 grams of the rich soil into a shallow dish, moistened it with distilled water, and exposed it to the air as an experiment on Fallow. The results showed a small gain of nitrogen.

Boussingault further found, that mycodermic vegetation went on in rich soil, and he considered the gains of organic nitrogen represented the remains of such vegetation; whilst the Fallow experiment indicated that the experimental plants had little to do with the action. His general conclusion was, that from the numerical results it must be believed, that the soil had fixed nitrogen; and he considered that, if there were no absolute proof, there was strong presumption, that the nitrogen of the air takes part in nitrification.

In the next year, 1860, he put into one large glass balloon a mixture of rich soil and sand, and into another a similar mixture, with cellulose in addition; each was moistened with distilled water, and the vessels were then closed up for 11 years. During this period, without cellulose rather more, and with cellulose rather less, than one-third of the nitrogen of the soil was nitrified; but in neither case was there any gain of total combined nitrogen. There was, indeed, in both cases, a slight loss of nitrogen indicated. Boussingault concluded that free nitrogen had not contributed to the formation of nitric acid.

The later results of Boussingault did not, therefore, confirm those he obtained in 1858 and 1859; and in answer to a letter from me he wrote in 1876, that he was not aware of any irreproachable observation which established the reality of the fixation of free nitrogen by the soil. He further stated his belief, that neither the higher plants, nor mycoderms, nor fungi (champignons), fix free nitrogen. He also maintained the same view in conversation in 1883.

SUMMARY AND GENERAL CONSIDERATIONS ON THE SOURCES OF THE NITROGEN OF OUR CROPS.

It did indeed seem that, in Boussingault's results of 1858 and 1859, there was *the germ of the germ theory* of the fixation of free

nitrogen, if such took place at all in connection with vegetation. But his own very distinct final conclusion against the supposition of such fixation by the agency of the lower organisms, seemed to indicate the necessity for caution in accepting much of the evidence which has been accumulating during the last few years.

It is evident that since experimenting with non-sterilised materials, and in free air instead of in closed vessels, has become more general, there has been a great accession of evidence which is held to show the fixation of free nitrogen. But, not only are the gains in some cases very small, and in others very large, but the modes of explanation are very different.

Thus, the various modes of explanation of the observed gains of nitrogen are:—that *combined* nitrogen has been absorbed from the air, either by the soil or by the plant; that there has been fixation of *free* nitrogen within the soil, by the agency of porous and alkaline bodies; that there has been fixation by the plant itself; that there has been fixation within the soil (or by the plant), by the agency of electricity; and finally, that there has been fixation under the influence of lower organisms, either within the soil itself, or in symbiotic growth with the higher plant.

The balance of the evidence recorded, is undoubtedly much in favour of the last mentioned mode of explanation. But of all the recent results bearing upon the subject, those of Hellriegel and Wilfarth, with certain leguminous plants, seem to be by far the most definite and significant. Accordingly, as we stated in October, 1888, in a postscript to our paper—"*On the Present Position of the Question of the Sources of the Nitrogen of Vegetation.*" (*Phil. Trans.*, 1889.)—it had been decided to institute somewhat similar experiments at Rothamsted. A preliminary series was, in fact, then in progress; and a more extended one has been undertaken in the present season, 1889. The results of these experiments show conclusively that, by the addition to the experimental soil, of a small quantity of the watery extract of a soil containing the appropriate organisms, there was greatly increased growth, and considerable gain of nitrogen; and there was, coincidently, a considerable development of the so-called leguminous nodules on the roots of the plants.

The conclusion is, not that the leguminous plant had directly utilised free nitrogen; but that the gain was due to the fixation of nitrogen in the growth of the lower organisms in the root-nodules; the nitrogenous compounds so produced, being taken up and utilised by the leguminous plant. It would seem, therefore, that in the growth of leguminous crops, such as Clover, Vetches, Peas, Beans, Lucerne, &c., at any rate some of the large amount of nitrogen which they contain, and of the large amount which they frequently leave as nitrogenous residue in the soil for future crops, may be due to atmospheric nitrogen so derived. It has yet to be ascertained, however, under what conditions a greater or less proportion of the total nitrogen of the crop will be derived, on the one hand from nitrogen compounds within the soil, and on the

other from such fixation. The probability seems to be, that the proportion due to fixation will be the less in the richer soils, and the greater in soils that are poor in combined nitrogen, and which are open and porous.

Even assuming that, in the case of leguminous crops, there will generally be some gain of nitrogen due to the symbiotic growth supposed, it will nevertheless be well to consider the facts of agricultural production, in their bearing on the question of the sources of the nitrogen of crops generally.

As already said, much of the investigation that has been undertaken in recent years, has been instigated by the assumption that there must exist natural compensation for the losses of combined nitrogen which the soil suffers by the removal of crops, and for the losses which result from the liberation of free nitrogen from its combinations under various circumstances. In some cases, however, the object seems to have been for the most part limited to an attempt to solve the admitted difficulty as to the explanation of the source of the whole of the nitrogen of the Leguminosæ.

As to the losses which the soil sustains by the removal of crops, Berthelot, for example, assumes that 50 to 60 kilog. of nitrogen will be annually removed from a hectare of meadow (= 45 to 54 lbs. per acre); and that, as only 10 kilog., or less, of this will be restored as combined nitrogen in rain, &c., there will be an annual loss of from 40 to 50 kilog. per hectare (= 36 to 45 lbs. per acre); so that, if there were not compensation from the free nitrogen of the air, the soil would become gradually exhausted. Further, he considers that the fact of the fixation of free nitrogen, not only explains how fertility is maintained, but how argillaceous soils, which are sterile when first brought into contact with the air, gradually yield better crops, and at length become vegetable moulds. Frank, again, assumes that the average loss of nitrogen by the removal of crops is 51 kilog. per hectare (= 45 lbs. per acre).

It is quite true, that a good hay crop may contain as much as 50 to 60 kilog. of nitrogen per hectare; but it may safely be affirmed that, in ordinary practice, even in the case of an unusually fertile meadow, such an amount is not annually removed for a number of years in succession, without the periodical return of manure supplying nitrogen; whilst, taking the average of soils, the annual yield will seldom reach the amount supposed, even with the ordinary periodic return, and without such return gradual exhaustion would be very marked. Indeed, it is well known that there is no more exhausting practice than the annual removal of hay without return of manure; so that, in point of fact, restoration in anything like the degree supposed, certainly does not take place. Next to the removal of hay, the consumption of the grass for the production of milk is the most, but still very much less, nitrogen-exhausting; whilst, if grass be consumed by store or fattening animals, the loss is very much less still; indeed, it is then very small.

Obviously, however, it is more important to consider, what is the probable average loss of nitrogen over a given area by the removal of crops generally, and not by that of grass alone. Moreover, in making such an estimate, it is not the total nitrogen of the crops that has to be reckoned; but, taking into account the return by manure, only the amount eventually lost to the soil. With the great variation according to circumstances, it is of course very difficult to estimate this at all accurately; but it may be stated, that two independent modes of estimate lead to the conclusion that, for Great Britain for example, the average annual loss of nitrogen is more probably under than over 20 lbs. per acre (= 22·4 kilog. per hectare). In fact, the loss by cropping under the usual conditions of more or less full periodical return by manure, is by no means so great as is generally assumed in discussions of this subject.

The loss of nitrates by drainage may, however, in some cases be considerable. There may also, under some circumstances, be loss by the evolution of free nitrogen. Such loss may take place in the manure heap; or in soils very heavily manured, as in market gardening, for example. But in ordinary agriculture such excessive manuring seldom takes place; and the soil is generally much poorer in nitrogen than in the cases of the experiments which have been adduced as showing great loss from rich soils. Loss may also take place when the soil is deficiently aërated; but, here again, the conditions of the experiments cited, in which considerable loss by evolution of free nitrogen was observed, are not the usual conditions of soils in actual practice. Indeed, the balance of evidence is against the supposition that there is a constant and considerable loss by the evolution of free nitrogen from arable soils which are only moderately rich in organic nitrogen, and which are fairly drained, either naturally or artificially.

On this point it may be mentioned that, in those of the field experiments at Rothamsted in which the unusual practice of applying farm-yard manure every year is adopted, it is found that there is considerable loss of nitrogen from the soil, beyond that known to be removed in the crops, and estimated to be lost in the drainage.

On the other hand, where no nitrogen has been applied for many years, and the amount of nitrogen in the surface soil is only about, or little more than 0·1 per cent., the loss of nitrogen by the soil over a long series of years corresponded approximately with the amounts removed in the crops, together with those estimated to be lost in the drainage. Again, when ammonium-salts are applied, even so late in the season as October or November, and drainage takes place soon afterwards, the drainage-waters will contain amounts of nitrogen showing a very direct relation to the different amounts of ammonia applied in the manure; but scarcely any of it as ammonia, nearly the whole existing as nitric acid; and this is the case although the drainage passes through twenty inches or more of raw clay sub-soil. Lastly, direct experiments have shown that there is a diminution in the amount of nitric acid in the soil down to a certain depth, varying according to the

root-range of the crop grown, and to the season, but that in the depths of the sub-soil below this point, the amount is again greater.

Again, M. Berthelot thinks it probable, though not absolutely established, that there is loss of nitrogen from the plant itself during growth. Long ago, we supposed that there was such loss; but careful consideration of the evidence relating to the subject has led us to the conclusion that it is not proved, and to believe that it probably does not take place. It may be observed, that when in his vegetation experiments M. Boussingault found a loss of nitrogen, there was coincidently some decaying vegetable matter, such as fallen leaves; and in somewhat parallel experiments at Rothamsted, no loss of nitrogen was found as a coincident of growth, and in the absence of dead vegetable matter. Indeed, if there were such loss during growth when there was no decay, either in M. Boussingault's experiments or our own, it must have been almost exactly balanced by corresponding gain; an assumption which is without any proof, but which has nevertheless had its advocates.

In fact it may be concluded that, under the existing conditions of practical agriculture in temperate climates, the annual loss of combined nitrogen over a given area, by cropping and otherwise, is by no means so great as has been assumed; that the restoration required to compensate the loss is, therefore, correspondingly less; and further, that the known facts relating to the maintenance or the reduction of the fertility of soils, do not point to the conclusion that such loss as actually does take place, is compensated by such restoration.

The well known accumulation of nitrogen which takes place in the surface-soil within a few years, when arable land is laid down to grass, is, it may be admitted, not conclusively explained. At the same time, there is abundant experimental evidence pointing to the conclusion that some deep-rooted leguminous plants derive a considerable quantity of nitrogen from the sub-soil; and there seems no reason to doubt that the deep-rooting plants of the mixed herbage of grass-land, whether leguminous or otherwise, may also avail themselves of sub-soil nitrogen; and, if so, it is to be supposed that they, like clover for example, will leave nitrogenous crop-residue in the surface-soil, the nitrogen of which has been derived from the sub-soil. In reference to this point it may be observed, that at Rothamsted there is per acre, in soil and sub-soil, to the depth at which the action of some deep-rooted, and large nitrogen-accumulating plants, has been proved, a store of about 20,000 lbs. of already combined nitrogen. It is true that whilst many other soils and sub-soils will contain as much, or more, many will contain much less.

It is indeed pretty certain, that at any rate much of the nitrogen gained by the surface-soil of land newly laid down to grass, has its source in the combined nitrogen of the sub-soil. Obviously, however, in view of results showing that leguminous crops may acquire nitrogen brought into combination under the influence of the symbiotic growth of lower organisms, the question suggests itself whether part of the

nitrogen accumulated in the surface-soil of land laid down to grass may not be due to such an action. On this point it may be remarked, that the "*nodules*" have been observed on the roots of some Leguminosæ growing in the mixed herbage of grass-land. On the other hand, it has to be borne in mind, that the proportion of leguminous plants in such mixed herbage is comparatively small. Further, it has yet to be determined whether the source of the nitrogen of the bacteroids in the nodules is exclusively free nitrogen, when the development proceeds in soil and sub-soil containing a large amount of combined nitrogen.

As to the supposition that the gains of nitrogen in argillaceous matters of very low initial nitrogen-contents, and which are attributed to the fixation of free nitrogen, serve to explain the gradual formation of vegetable soils, there cannot be any doubt that, so far as nitrogen is concerned, the natural fertility of most soils is at any rate mainly due to the accumulation of ages of natural vegetation, with little or no removal of it, by animals or otherwise; and if the amounts of nitrogen even now brought into combination over a given area under the influence of electricity in equatorial regions, were not exceeded in the earlier periods of the history of our globe, that would probably be sufficient, with growth and with little or no removal, through the ages which modern science teaches us to reckon upon, to account for most, if not the whole, of the accumulations in natural grass, or forest lands; and it is these which have to a great extent furnished us with our meadows and pastures, and arable soils.

Frequently the natural forests have been on the more elevated, or the more undulating lands, and the soils they have formed are less rich than the prairie lands for the most part found in the valleys or on the plains. Taking the vast areas of fertile natural prairie on the American continent for example, sometimes of several feet in depth, it may be estimated that, in such cases, each foot of depth will contain from 6,000 to 10,000 lbs., or even more, of combined nitrogen per acre; and the probable time of these accumulations at any rate obviates the necessity of assuming the intervention of the free nitrogen of the atmosphere, brought into combination by the soil, or by the plants themselves. So far, however, as leguminous growth may have contributed to the result, it is, in view of existing evidence, to be supposed that some at any rate of the accumulation may have been due to fixation under the influence of the symbiotic growth of lower organisms and the higher plants.

Further, the history of agriculture so far as it is known, indicates that arable soils without supplies by manure from external sources, do, as a matter of fact, gradually become less fertile. This, as a rule will take place more rapidly in undulating or high forest lands, than in the natural grass or prairie lands of the plains.

Again, if we compare the amount of nitrogen in the surface-soil of permanent grass land, with that of adjoining land of the same original character, but which has for some time been under arable culture, we find that the latter is much poorer in nitrogen. In illustration, it may

be stated, that whilst the surface-soil of the grass land at Rothamsted contains from 0·25 to 0·30 per cent. of nitrogen, that of the corresponding arable land contains only from 0·1 to 0·15 per cent. The arable soil has, in fact, originally been covered with natural vegetation of some kind, with comparatively little removal, and consequent accumulation; whilst, under arable culture, much of the accumulated nitrogen has been used up, and the loss has not been compensated by free nitrogen brought into combination within the soil, either under the influence of electricity or of lower organisms. Indeed, whether or not there is any restoration of the kind supposed, a consideration of the origin of soils generally, and of the history of agriculture in different countries, leads to the conclusion that the losses of combined nitrogen by cropping, and in other ways, are not compensated by corresponding amounts of free nitrogen constantly brought into combination.

The Rothamsted Field Experiments have now been continued long enough to afford some pertinent examples bearing upon this subject.

Thus, in the case of the plots under continuous wheat, continuous barley, alternate wheat and fallow, and continuous root-crops, with mineral, but without nitrogenous manure, the average annual yield of nitrogen in the crops, has only been about or under 20lbs per acre; the amount has declined to less than the average in the later years; and, coincidently with the continuous and diminishing growth, the percentage of nitrogen in the surface-soil has been considerably reduced. The loss by the removal of even such small crops, together with that by drainage, has, therefore, as a matter of fact, not been compensated by free nitrogen brought into combination, either by the plants, or within the soil.

In the field where the Leguminous crop—Beans, had been grown 25 years out of 32, with mineral but without nitrogenous manure, and had yielded less than average agricultural crops, the per-centage of nitrogen in the surface-soil was also greatly reduced.

In another field, where the Leguminous crop—Red Clover, had been sown 12 times in 30 years, the Clover failed many times, the yield of nitrogen in the crops very greatly diminished, and the per-centage of nitrogen in the surface-soil was greatly reduced.

Again, in rich garden-soil, where Red Clover has been grown for 36 years consecutively, and has yielded throughout good, but gradually diminishing crops, it was found, after the first 22 years, that the nitrogen in the surface-soil had been reduced from 0·5095 to 0·3634 per cent., or by about one-third.

Even in an actual course of rotation, of Turnips, Barley, Clover or Beans, and Wheat, with mineral, but without nitrogenous manure, the per-centage of nitrogen in the surface-soil has been much reduced; whilst, in a parallel rotation in which Fallow takes the place of the Clover or Beans, the reduction is still greater.

Thus, in all the cases cited, including Gramineous, Cruciferous, Chenopodiaceous, and even Leguminous crops, and a rotation of crops, grown for many years in succession without nitrogenous manure, and yielding

comparatively small and declining amounts of nitrogen in the produce, there has, coincidently, been a considerable reduction in the amount of nitrogen in the surface-soil. There has, in fact, not been compensation from the free nitrogen of the air, or at any rate not at all in amount corresponding to the annual losses.

Lastly, Grass-land which, under the influence of a full mineral manure, including potash, but without any supply of nitrogen for more than thirty years, has grown crops containing rather large amounts of comparatively superficially rooting leguminous herbage, which has been succeeded by increased amounts of gramineous herbage, and has, under those conditions, yielded about the same amount of nitrogen per acre as M. Berthelot assumes to be the average produce of a meadow, but it has done so, only with coincident great reduction in the nitrogen of the surface-soil.

Whether, therefore, we consider the facts of agriculture generally, or confine attention to special cases under known experimental conditions, the evidence does not favour the supposition that a balance is maintained by the restoration of nitrogen from the large store of it existing in the free state in the atmosphere. Further, our original soil-supplies of nitrogen are, as a rule, due to the accumulations by natural vegetation, with little or no removal, over long periods of time. Or, as in the case of many deep subsoils, the nitrogen is partly due to animal remains, intermixed with the mineral deposits. The agricultural production of the present age is, in fact, so far as its nitrogen is concerned, largely dependent on previous accumulations; and, as in the case of the use of coal for fuel, there is not coincident and corresponding restoration, so in that of the use or waste of the combined nitrogen of the soil, there is not evidence of coincident and corresponding restoration of nitrogen from the free to the combined state.

In the case of agricultural production for sale, without restoration by manure from external sources, a very important condition of the maintenance of the amount of nitrogen in the surface-soil, or of the diminished exhaustion of it, is the growth of plants of various range and character of roots, and especially of leguminous crops. Such plants, by their crop-residue, enrich the surface-soil in nitrogen. It is, as a rule, those of the most powerful root-development that take up the most nitrogen from somewhere; and this fact points to a sub-soil source. But, independently of this, which obviously may be held to be only evidence of the necessity of obtaining water and mineral matters from below, in amount commensurate with the capability of acquiring nitrogen, direct experimental evidence can leave no doubt that such plants do obtain at any rate much of their nitrogen from the sub-soil. The question arises—whether or not the whole of the nitrogen of our crops comes from combined nitrogen, in the soil and sub-soil, in manure, and in rain, &c., or whether part of it is in some way derived from the free nitrogen of the atmosphere? Cumulative evidence points to the conclusion that, in the case of our gramineous, our cruciferous, our chenopodiaceous, and our solaneous crops, free nitrogen is not the

source. Recently acquired evidence indicates, however, that it may, indirectly, be the source of at any rate some of the nitrogen of Leguminosæ. It would further seem, that the development of the organisms capable of bringing free nitrogen into combination, if not an essential coincident of the growth of some leguminous plants, is at any rate favoured by such growth.

G. H. HARMER, "WILTS AND GLOUCESTERSHIRE STANDARD" OFFICE, CIRENCESTER.

[*From the* PROCEEDINGS OF THE ROYAL SOCIETY, Vol. 47.]

"New Experiments on the Question of the Fixation of Free Nitrogen. (Preliminary Notice.)" By Sir J. B. LAWES, Bart., LL.D., F.R.S., and Professor J. H. GILBERT, LL.D., F.R.S. Received (in part) and read January 9, 1890.

Received January 9.

In a paper presented to the Royal Society in 1887—1888, and printed in vol. 180 of the 'Philosophical Transactions,' we discussed the history and the present position of the question of the sources of the nitrogen of vegetation. We referred to the conclusions arrived at about thirty years ago from the results of Boussingault and from those obtained at Rothamsted, up to that time. We gave the results of some experiments which had been recently made at Rothamsted in connexion with the subject, and reviewed the evidence and conclusions of others published within the last few years.

It was considered that the earlier results obtained by Boussingault,

and at Rothamsted, under conditions in which the action both of electricity and of microbes was excluded, were conclusive against the supposition that, under such conditions, the higher chlorophyllous plants can directly fix the free nitrogen of the atmosphere, either by their leaves or otherwise. Others have, indeed, come to the conclusion that at any rate some plants do directly fix the free nitrogen of the air by their leaves. We believe, however, that there is, up to the present time, no evidence which can be held to be conclusive in favour of such a view.

It was pointed out how large was the store of already existing combined nitrogen in many soils and subsoils, and evidence was adduced to show that even *Leguminosæ* derive, at any rate a considerable amount of nitrogen from nitric acid within the soil and subsoil; and, further, that it was, as a rule, those having the most powerful root-development that took up the most nitrogen from somewhere; and it was considered that this fact pointed to a subsoil source.

Upon the whole it was concluded that, at any rate in the case of our gramineous, our cruciferous, our chenopodiaceous, and our solaneous crops, atmospheric nitrogen was not the source. It was admitted, however, that existing evidence was insufficient to explain the source of the whole of the nitrogen of the *Leguminosæ*.

According to some of the more recent experimenters, the fixation of free nitrogen is not limited to our leguminous crops; and the modes of explanation of the gains of nitrogen observed are extremely various. Thus, it is assumed—that combined nitrogen has been absorbed from the air, either by the soil or by the plant; that there is fixation of free nitrogen within the soil by the agency of porous and alkaline bodies; that there is fixation by the plant itself; that there is fixation within the soil by the agency of electricity; and, finally, that there is fixation under the influence of micro-organisms within the soil, with, or even without, the accompanying growth of higher plants.

The balance of the evidence recorded seemed to be undoubtedly in favour of the supposition that there is fixation under the influence of micro-organisms or of other low forms within the soil, and of all the various results which were discussed, those of Hellriegel and Wilfarth were considered to be by far the most definite and significant; pointing to the conclusion that, although the higher chlorophyllous plants may not directly utilise the free nitrogen of the air, some of them, at any rate, may acquire nitrogen brought into combination under the influence of lower organisms, the development of which is, apparently, in some cases, a coincident of the growth of the higher plant whose nutrition they are to serve. Such a conclusion is, however, of such fundamental importance that it seemed very desirable that it should be confirmed by independent investigation.

Accordingly, as stated in a postscript to our paper, dated October, 1888, it had been decided to institute experiments at Rothamsted on similar lines, and a preliminary series was then in progress. A second and more extended series has been conducted in the past season, 1889. It is proposed to give, on the present occasion, a description, and some of the numerical results, of the experiments made in 1888, and a description, and some illustrations, of the growth in those of 1889.

It was in 1883 that Hellriegel commenced a comprehensive series of vegetation experiments in pots, in which he grew agricultural plants of various families in washed quartz sand. To all of the pots nutritive solutions containing no nitrogen were added; to one series nothing else was supplied; to a second a fixed quantity of nitrogen as sodium nitrate; to a third twice as much; and to a fourth four times as much was added. The result was that, in the case of the Gramineæ, and some other plants, the growth was largely proportional to the nitrogen supplied, whilst in that of the Papilionaceæ it was not so. In the case of these plants, that of peas for example, it was observed, however, that in a series of pots to which no nitrogen was added, most of the plants were apparently limited in their growth by the amount of nitrogen which the seed supplied; whilst here and there a plant growing ostensibly under the same conditions would develop very luxuriantly; and, on examination, it was found that whilst no nodules were developed on the roots of the plants of limited growth, they were abundant on those of the plants that grew luxuriantly.

In view of this result, Hellriegel instituted experiments to determine whether, by the supply of the organisms, the formation of the root-nodules, and luxuriant growth, could be induced, and whether by their exclusion the result could be prevented. To this end, he added to some of a series of experimental pots 25 c.c., or sometimes 50 c.c., of the turbid extract of a fertile soil, made by shaking a given quantity of it with five times its weight of distilled water. In some cases, however, the extract was sterilised. In those in which it was not sterilised there was almost uniformly luxuriant growth, and abundant formation of root-nodules; but with sterilisation there was no such result. Consistent results were obtained with peas, vetches, and some other Papilionaceæ; but the application of the same soil-extract had no effect in the case of lupins, serradella, and some other plants of the family which are known to grow more favourably on sandy than on loamy or rich humus soils. Accordingly, he made a similar extract from a diluvial sandy soil where lupins were growing well, in which it might be supposed that the organisms peculiar to such a soil would be present; and, on the application of this to nitrogen-free soil, lupins grew in it luxuriantly, and nodules were abundantly developed on their roots.

The Experiments at Rothamsted in 1888.

This preliminary series comprised experiments with peas, blue lupins, and yellow lupins. The peas were grown—

1. In washed sand, with the ashes of the plant added; but no supply of combined nitrogen beyond a small determined amount in the washed sand and that in the seed sown.

2. In similarly prepared sand, but seeded with 25 c.c. of the turbid watery extract from a rich garden soil.

3. Duplicate of No. 2.

4. In the rich garden soil itself.

Each of the two descriptions of lupin was grown—

1. In sand prepared as for the peas, but with lupin-plant-ash instead of pea-plant-ash added.

2. In the same washed sand, &c., but seeded with 25 c.c. of the turbid watery extract from a sandy soil where lupins had grown luxuriantly.

3. In the lupin sandy soil itself.

4. In rich garden soil.

The twelve pots were arranged in a small greenhouse; and distilled water, free from ammonia, was used for watering.

The sand employed was a yellow sand from Flitwick, in Bedfordshire, and was of the same description as is used by gardeners in the neighbourhood for potting. It proved, however, not to be a very pure sand. Thus, after the stones and coarser portions had been removed by sifting, the remainder was several times washed, first with well-water and afterwards with distilled, the turbid washings being poured off; yet it was found to contain after being dried finally for a short time in a water-bath, and mixed with the plant-ash as mineral food, nitrogen as under :—

	Per cent. nitrogen.
Determined by soda lime	0·00287
Determined by copper oxide.....	0·00245
Mean.....	0·00266

The sandy soil in which lupins had grown, and from which the watery extract was made for seeding the pots where the lupins were to grow, was still less pure; and it, of course, was not washed, and was only dried at about 24° C.; and, excepting that visible organic matter was removed by sifting and picking, it was used in its natural state as received. Duplicate determinations of nitrogen were made by soda-lime, in the lupin sand alone, and as used after mixture with the lupin ash. The following are the mean results, in each case, calculated on the dry sand :—

	Per cent. nitrogen.
In lupin sand, alone	0·0863
In lupin sand, with blue lupin ash.....	0·0826
In lupin sand, with yellow lupin ash	0·0888
Mean.....	0·0859

It may be stated that, in this country, lupins are only grown as an agricultural crop, as food for sheep, on poor, sandy soils, on which little or nothing else will grow. The sand obtained for the purposes of the experiments was from land which had been reclaimed from a common in Suffolk, and on which no corn crop would grow; but on which, when subsequently sown with blue lupins, they had grown as high as the hurdles. It is stated, however, that lupins grow better on good land, but that they are grown on sandy wastes because they will thrive on them when no other crop will.

The garden soil, in the condition as analysed, contained 10·12 per cent. of moisture, and two determinations of nitrogen by soda-lime gave 0·3902 and 0·3936, mean 0·3919, corresponding to 0·4360 per cent. on the soil dried at 100° C.

The pots used were made of glazed earthenware; and were about 7 inches high, 6 inches in diameter at the top, and 5½ inches at the bottom, inside. They had a hole half an inch in diameter at the bottom for drainage, and another at the side near the bottom, into which, outside, a glass tube bent upwards was fixed for aëration; the tube being lightly closed with cotton-wool to prevent insects getting in. The pots rested on slips of thick sheet glass, placed in basins of the same glazed earthenware as the pots.

The mineral nutriment used was as follows:—For the peas, a mixture of 6 parts of pea-straw-ash and 1 part of pea-corn-ash; for the blue lupins, a mixture of 3 parts of blue lupin-straw-ash and 1 part of blue lupin-corn-ash; for the yellow lupins, a mixture of 4 parts of yellow lupin-straw-ash and 1 part of yellow lupin-corn-ash. In each case the greater part of the mixed ash was suspended in distilled water, and sulphuric acid added until there was a slight acid reaction; the rest of the ash was then added, and the whole evaporated to dryness and re-ignited. The ash was then very slightly alkaline to litmus. The so-prepared ashes were mixed at the rate of 0·5 per cent. with the greater part of the sand put into the pots; the remainder of the sand at the top of the pot being without ash.

The drain hole at the bottom of each pot was loosely covered with a piece of thick glass, 1 lb. of broken, washed, and dried flint was then put in, next the sand with ash, and lastly the sand without ash. The pots held from 7 to 9 lbs. of the yellow Flitwick sand, from 6 to 7 lbs. of the lupin sand, and about 4½ lbs. of the garden soil.

The soil extracts, supposed to supply the organisms, were made by shaking, in a large stoppered bottle, 1 part of the garden soil or lupin sand with 5 parts of distilled water; and after the heavier portions had settled down, syphoning off the turbid liquid, which was then passed through platinum gauze to separate any floating matter. The liquid was again shaken before taking the quantity required for seeding the soils, or for analysis. Determinations of nitric nitrogen by Schlœsing's method, and of total nitrogen by copper oxide, gave the following results:—

	Per cent.		In 25 c.c. extract.	
	Nitric nitrogen.	Total nitrogen.	Nitric nitrogen.	Total nitrogen.
	Per cent.	Per cent.	Milligram.	Milligram.
Garden soil extract....	0·000371	0·003159	0·093	0·790
Lupin sand extract....	0·000110	0·001184	0·028	0·296

It is thus seen that the 25 c.c. of the garden soil extract used for seeding contained little more than $\frac{3}{4}$ of a milligram, and the 25 c.c. of the lupin sand extract little more than $\frac{1}{4}$ of a milligram of nitrogen; quantities which are quite immaterial considered as a supply of combined nitrogen.

The Seeds.

The peas were of the description known as Maple field-peas. Four lots, each of 100 seeds, weighed 27·554, 27·460, 27·218, and 27·506 grams; giving an average weight per seed of 0·2743 gram. A large number of single seeds was then weighed, and those only retained for sowing or analysis which gave within 5 milligrams of the mean weight.

In the case of the blue lupins the largest and smallest seeds were picked out and rejected. Of the remainder, four separate lots of 100 each weighed 19·2290, 19·9215, 18·7960, and 19·4580 grams, giving an average weight per seed of 0·1935 gram. A large number of single seeds was then weighed, and those only kept for use the weight of which was within 5 milligrams of the average weight.

From the yellow lupin seed the largest were removed by sifting, and the smallest and those of a dark colour were picked out. Of the remainder, three separate lots of 100 each weighed 12·1060, 11·9640, and 11·6180 grams, giving an average weight per seed of 0·1190 gram. From these, seeds were selected for use which weighed within 5 milligrams of the average weight.

Determinations of dry matter, and of nitrogen, in the seeds, gave the following results:—

	Dry matter at 100° C.	Nitrogen.					
		In fresh.				In dry matter.	
		By soda-lime.			By copper oxide.	By soda-lime. Mean.	By copper oxide.
		Expt. 1.	Expt. 2.	Mean.			
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Maple peas..	93·26	3·537	3·621	3·579	3·531	3·837	3·787
Blue lupins..	94·03	5·105	5·098	5·101	5·364	5·425	5·705
Yellow lupins	94·63	6·649	6·569	6·609	6·404	6·984	6·767

It should be stated, as applicable to the whole of the results as well as to those recorded in the foregoing table, that nitrogen was determined by burning in a vacuum with copper oxide, and collecting and measuring the nitrogen and nitric oxide. In all cases, however, where there was sufficient material, determinations were also made by the soda-lime method, as a check. Nitrogen as nitrates was determined by Schlœsing's method. The copper oxide determinations given in the table, which are those used in the subsequent calculations, were made upon three or four of the average selected seeds, ground up with the copper oxide; whilst the check soda-lime determinations were made on quantities taken from a bulk of ground seeds.

The Vegetation Experiments in 1888.

It was intended to commence the experiments early in the summer, but the pressure of other work and the preparations necessary for the experiments themselves, prevented the sowing of the seed until early in August. Nevertheless, the results obtained in this initiative series were not only of value as affording experience on various points, of which advantage has been taken in the conduct of the more extended series made in 1889, but, as will be seen, they have afforded important evidence on the main point of enquiry itself.

The broken flints, the sand with ash, and the sand without ash, or the garden soil, as the case may be, were weighed and put into the respective pots at the laboratory, taken to the glass-house on August 4, and watered with ammonia-free distilled water. All the seeds were sown on August 6. Three accurately weighed seeds were put into each pot.

From the first, the peas germinated and grew well in each of the

four pots; but in each of the four pots of blue lupins, and in each of the four of yellow lupins, one or more seeds failed, and had to be replaced; and in some cases these also failed There was in fact failure, not only in the poor Flitwick sand, but in the less poor lupin sand, and also in the rich garden soil. It is admittedly very difficult to secure healthy growth with lupins in pots. On discussing the matter with Hellriegel, at the meeting of the *Naturforscher Versammlung*, at Cologne, in September, 1888, he stated that it had required the experience of several years to insure favourable growth of lupins under such circumstances; and that one essential condition seemed to be that the soil must be kept open and porous; a result which, even with sand, was seldom attained if the dry materials were put into the pot, and then water poured on; the better plan being to bring the sand to a proper condition of moisture by well mixing water with it by degrees out of the pot, and then putting it lightly into the pot. It is also important that the mineral matter added to the soil should be quite neutral.

The failures are well illustrated by the photographs exhibited. Thus, in spite of the re-sowings, there were, on November 3, that is after three months since the first sowing of blue lupins, three plants in pot 1, with the yellow Flitwick sand without soil-extract; only two in pot 2, with the same sand and soil-extract seeding; none in pot 3 with the lupin sand itself, from which the soil-extract was prepared; and three, but of very varying size, in pot 4, with garden soil.

Then the photographs of the yellow lupins show that, in pot 1, with the yellow Flitwick sand, there remained only two plants; in pot 2, with the same sand and lupin soil-extract seeding, only two; in pot 3, with the lupin sand itself only two; and in pot 4, with the garden soil, only two plants.

We shall call attention to the development of the roots, and of nodules on them, in the case of the blue and yellow lupins, further on. Nitrogen determinations have also been made in most of the products; but, as with both blue and yellow lupins, there was actually less growth with than without the lupin sand extract, assumed to supply the organisms, we do not propose to discuss the analytical results on the present occasion; but, so far as that part of the subject is concerned, we shall confine attention to results relating to the peas, of which the growth was much more satisfactory, and the analytical results afford very important indications.

As already said, the peas in each of the four pots germinated and grew well. Throughout, those in the garden soil were more luxuriant than those in either of the other pots. Pots 2 and 3 were each seeded with 25 c.c. of the garden-soil-extract on August 13, that is just a week after the sowing of the seed. For some time, however, the plants in pot 1, with the sand without soil-extract, showed more

growth, and better colour, than those in either pot 2 or pot 3 with the soil-extract seeding. Indeed, it was not until about the middle of September, that is four or five weeks after the seeding with soil-extract, that the plants in pots 2 and 3 began to show a darker green colour than those in pot 1 without the soil-extract. The indication was, however, so striking, that on September 25 it was decided to count the leaves, and to estimate the relative area of leaf-surface, on the plants in the different pots. For this purpose, the leaves were classified into those which were dead, those that were dying, those which were changing colour, and those which were still bright green. It must suffice here to show the number, and the estimated relative area, of the total leaves in each case, on September 25, when the first counting and estimates were made, on October 17, on November 14, and on December 14, when the plants were cut. The following table summarises these results. The first four columns show the total number of leaves, and the second four the estimated relative leaf-surface, that of the plants of pot 1 (without soil seeding) on September 25, being taken as 100.

Peas, 1888.

	Number of leaves.				Estimated relative leaf-surface.			
	Pot 1.	Pot 2.	Pot 3.	Pot 4.	Pot 1.	Pot 2.	Pot 3	Pot 4.
September 25.....	144	140	120	164	100	67	58	128
October 17.....	188	200	184	216	143	172	158	242
November 14.....	244	300	244	280	170	249	245	328
December 14	382	540	390	434	267	481	434	463

It is thus seen that, on September 25, after it had been observed that the plants in pots 2 and 3, with the soil-extract seeding, had begun to show a darker green colour than those in pot 1 without the soil-extract, they nevertheless, up to that date, showed both a less number of leaves, and considerably less leaf-surface, than the plants in pot 1. It is not very clear why the plants with the soil-extract seeding should have remained so long in a comparatively backward condition. It may be that the result was only accidental, depending on the character of the seeds, or on the fact that pot 1 stood at the southern end of the row, and nearest the glass. The alternative is that, in the early stages of development of the organisms supplied in the soil-extract, and of the resulting nodules, the growth of the main plant was, in some way, retarded. The figures show, however, that, from

this date, the plants in pots 2 and 3 with the soil-extract, gradually gained upon those in pot 1 without it, both in number of leaves, and in leaf-surface; until, when the plants were taken up on December 14, those in pots 2 and 3 showed 540 and 390 leaves, against only 382 on those in pot 1; and the plants of pots 2 and 3 showed 481 and 434 of leaf-surface, against only 267 in pot 1. It is seen that there is here clear evidence of increased growth under the influence of the soil-extract seeding.

Photographs of the 4 pots of plants were taken on September 1, on September 22, on October 6, and lastly on November 3, about five weeks before the taking up of the plants, and they indicate relative progress consistently with the estimates given in the foregoing table.

In regard to the general character of growth it should be stated that, in all the pots, the upper portions of the plants obviously developed at the expense of the lower; the leaves of which gradually lost colour, and died off, whilst the stems and the leaves of the upper portion increased in growth; those in pots 2, 3, and 4, continuing to vegetate, and to maintain their bright green colour, up to the end; whilst those in pot 1 had shown more exhaustion, and maintained much less colour. There was, however, as was to be expected so late in the season, no indication of flowering in any of the pots.

It should be further stated, that the plants in all the pots commenced rather early to show signs of mildew, which increased very considerably, especially on the lower portions of the plants, in the later stages of growth. This was, perhaps, not to be wondered at, considering that the greenhouse was in the midst of allotment gardens, and that the plants were unavoidably subjected to considerable changes as to temperature and moisture of the atmosphere. Ventilation was, however, secured as far as practicable.

The next point to consider is, the actual and comparative development of the roots, and of nodules on them, in the different pots, with their different soil conditions. As the roots had to be preserved without any loss, for analysis, the mode of dealing with them for the purposes of examination had to be very carefully considered, and was necessarily more restricted than if examination had been the only object. After the above-ground growth had been cut off and removed, the pots, with their moist soil and roots, were kept in a warm dry place until the examination commenced. The block of soil was carefully turned out on to glazed cartridge paper, with as little shaking or disturbance as possible, and notes were at once taken as to the distribution of the roots, so far as it was then apparent. The sand or soil was then removed little by little, until the roots were left nearly bare. Further notes being then taken, the remaining sand or soil was removed as far as possible by washing in a beaker

with a little distilled water. The roots were then spread out upon paper, and so photographed, and finally noted upon.

Enlarged photographs of the roots of the plants grown in pot 1, with the yellow sand without soil-extract seeding, in pot 2, with the same sand and soil-extract seeding, and in pot 4, in the garden soil, were exhibited.

The roots in pot 1, with the yellow sand without soil-extract seeding, showed a densely matted mass of fibre, those of the different plants being considerably interwoven; and although a few fibres reached the bottom of the pot, and distributed through the flints, by far the greater portion was accumulated within the top 4 inches of the sand; and, notwithstanding there was here no soil-extract seeding, there were many nodules on the roots, but they were fewer, and generally much smaller, than on the roots grown with soil-extract seeding; they were also less characteristically accumulated near the surface, and more distributed along the root-fibres. There were, however, some agglomerations of nodules. Comparing this result with that obtained in 1889, with a purer and sterilised sand, there can be little doubt that the development of nodules, and the comparatively luxuriant growth, in this pot without soil-extract seeding, are to be attributed to the impurity, and non-sterilisation, of the sand.

The roots in pot 2, with soil-extract seeding, also showed a dense mass of fibre, which, however, extended from the top to the bottom of the soil, penetrated the layer of flints, and distributed over the bottom of the pot. In fact, the roots were much more generally distributed throughout the soil, and less accumulated within the surface layers, than in pot 1. The most developed root of the three, had three large agglomerated nodules, each with some scores of protuberances, somewhat as on a raspberry or mulberry. The other plants also showed similar nodules, but of a smaller size. There were also a number of small clusters distributed over the rootlets, but very few single nodules, differing in this respect from the character of development observed in pot 1.

In pot 3, also with soil-extract seeding, each of the three plants had developed a mass of root-fibre extending throughout the soil from the top to the bottom; though the greatest quantity was within the first 6 of the 7½ inches of depth. There were large agglomerations of nodules on the roots of each plant. There were, besides, many small clusters, and here and there single nodules. By far the most of the nodules were within the top 3 inches of the sand; but one considerable bunch was found as low as 4 inches from the surface. As in the other cases, the nodules were grey, and much lighter in colour than the roots on which they grew.

Each of the three plants in pot 4, with the garden soil, had a

stouter main root than any of those in the other pots. From the side branches there proceeded a large amount of fine root-fibres, which extended throughout the whole soil, those from the different plants being much interwoven. The roots extended round the sides and along the bottom of the pot, much more than in either of the other pots. A photograph was, therefore, taken of the block of soil as it came out of the pot, showing this special character of root-development. There were three small clusters of nodules on the roots of each of the three plants, one or two smaller bunches, and here and there a single nodule. But the clusters were much smaller, the total number of nodules was much less, and they were more distributed throughout the soil, in this pot with rich garden soil, than in either of the others, even than in pot 1, without any soil-extract seeding. As the description shows, the root-development was at the same time much greater than in either of the other pots. To this point we shall have to recur again, but it may be remarked in passing, that the greater development of root and root-fibre, and the less development of the root-nodules, in the soil which itself supplied abundance of nitrogenous, as well as of other nutriment, is consistent with the observations of some other experimenters; but it is, on the other hand, inconsistent with the observations and views of others.

Finally in regard to the relative development of root-nodules under the different conditions, the evidence is clear, that there was a greatly enhanced development of them under the influence of the soil-extract seeding; and that, coincidently with this, there was a considerably increased growth of the above-ground parts of the plant.

The distinctly less development of root-nodules in the rich garden soil, than in the sand with soil-extract seeding, as observed in the case of the peas, was, however, not found in that of the lupins, as the following notes on the roots of the lupins grown in 1888, will show.

In pot 5, with the impure yellow sand, but without soil-extract, eventually three plants of blue lupins grew. From the short, thick, main root, many branches proceeded, extending from the top to the bottom of the soil; those plants having the largest above-ground development had also the most root. The branches were fleshy and succulent, and thicker at a distance from the main stem than near it. No nodules were observed on the roots in this pot.

In pot 6, with lupin-soil-extract, but with only two plants, the roots were of the same general character as to branching, extension, fleshiness, and succulence, as those in pot 5. There was, however, one nodule, about the size of a pea, on a root-fibre on one of the two plants.

In pot 7, with the lupin sand itself, there was no plant.

In pot 8, with the garden soil, there were three plants, two of them small ones from more recent sowings than the other, and with much less root development; but there were three or four nodules or swellings on the root-fibres of each plant. The largest and oldest plant showed a very great development of root, extending throughout the soil, round the sides, and along the bottom of the pot. On the main root, which was thick and strong down to about 5 inches, there were two large swellings or nodules about 3 inches from the surface, each of which, unlike the bunches of nodules on the pea roots, appeared externally to be single and solid, but indented. There were, besides, nineteen small swellings on the root-fibres, of the same colour as the root itself, and whether these were nodules or not was not very obvious.

In pot 9, in the yellow sand without soil-extract, there were two plants of yellow lupins. With less above-ground growth, there was also considerably less root development, than under the same soil conditions with the blue lupins (pot 5). As in the case of the blue lupins, there were, however, no nodules.

In pot 10, with lupin-soil-extract seeding, there were two small plants, also with small root-development, but throwing out much fine fibre near the surface, and then slender branches to the bottom of the pot. There were here, again, no nodules.

In pot 11, with the lupin sand, there were two plants, one very much larger than the other. There was a swelling on the thick main root of the smaller plant, but there were no nodules on the rootlets. The larger and older plant developed a dense mass of both fleshy and fine fibrous root. The main root, about 1 inch from the surface, was encased by a large swelling. The roots extended from the top to the bottom of the soil. No nodules were observed on the rootlets, but there was an abundance of root-hairs.

In pot 12, with garden soil, there were two plants. The stout, woody, main root, extended deeper than in the other pots; and there were many branches, extending round the sides and along the bottom of the pot. The larger plant had two swellings on the main root, about 1½ inch from the surface, each of the size of a field bean; also three small nodules on the root-fibres. The smaller plant had one indication of such a swelling on the main root, and twelve nodules on the root-fibres, three the size of a pea, three half as large, and six very small. The larger were 1 or 2 inches from the surface, the others lower, one 6 inches down. There was more fine fibre, but very much less development of root-hairs than in pot 11.

Thus, in the case of both blue and yellow lupins, there were no nodules without soil-extract, and only one with the lupin soil-extract seeding. In the lupin soil itself there was some indication, but in the garden soil there was, with both descriptions of lupin, a much

more marked development, both of swellings on the main roots, and of nodules on the root-fibres. The very meagre development of nodules both with lupin-soil-extract seeding, and in the lupin-soil itself, in 1888, when, as will be seen further on, the result was so different in 1889, suggests the question whether the lupin-sand of 1888 had been too much dried, and so sterilised.

The Analytical Results.

We will now turn to the evidence afforded by analysis, as to the difference in the amount of growth, and especially as to the difference in the amount of nitrogen assimilated, in the peas grown under the different conditions.

The following table shows the percentages of ash, and of nitrogen determined by copper oxide (each calculated on the dry substance), in the stems and leaves together, and in the roots, of the plants in the different pots.

	Per cent. in dry substance.			
	Ash.		Nitrogen.	
	In stems and leaves.	In roots.	In stems and leaves.	In roots.
	Per cent.	Per cent.	Per cent.	Per cent.
Pot 1. Sand, without soil-extract	19·70	28·67	2·904	2·574
Pot 2. Sand, with soil-extract..	16·07	36·75	4·900	3·195
Pot 3. Sand, with soil-extract..	13·87	23·26	4·006	3·357
Pot 4. Garden soil	9·17	20·44	4·534	2·791

It is remarkable how much lower is the percentage of ash in the dry substance of the more normally-developed plants grown in the garden soil, than in that of those grown in the sand with plant-ash added. There can be no doubt that the amount of soluble mineral matter provided in the quantity of ash used was excessive; and less has been supplied in the experiments of 1889. The percentage of ash in the dry substance of the roots is, however, in all cases high, but doubtless some adherent sand would be included.

The differences in the percentage of nitrogen in the dry substance of the differently grown plants are consistent with the known characters of growth. Thus, the lighter colour, and the comparatively restricted growth, of the plants in pot 1, indicated nitrogen exhaustion; and the

percentage of nitrogen in the dry substance, of both the above-ground and the under-ground produce, is lower than in either of the other cases. It may be further noted, that the roots grown in pots 2 and 3 with the soil-extract, and with so much greater development of nodules than in either pots 1 or 4, at the same time contained a considerably higher percentage of nitrogen in their dry substance.

The next table shows the actual quantities of dry substance, of ash, and of nitrogen, in the separated, and in the total, products of growth.

	Actual amounts in the produce.								
	Dry substance.			Ash.			Nitrogen.		
	In stems and leaves.	In roots.	In whole plant.	In stems and leaves.	In roots.	In whole plant.	In stems and leaves.	In roots.	In whole plant.
	grams.	grams.	grams.	grams.	gram.	grams.	gram.	gram.	gram.
Pot 1	7·423	2·600	10·023	1·462	0·745	2·207	0·2153	0·0669	0·2822
Pot 2	9·368	2·409	11·777	1·505	0·885	2·390	0·4591	0·0770	0·5361
Pot 3	9·411	1·748	11·159	1·305	0·407	1·712	0·3771	0·0587	0·4357
Pot 4	12·808	2·846	15·654	1·175	0·582	1·757	0·5816	0·0794	0·6600

It is seen that there is more dry substance in the above-ground growth, but less remaining in the roots, in pots 2 and 3 with the soil-extract than in pot 1 without it. In the whole plant there is, of dry substance with soil-extract, about 11¾ grams in pot 2, and more than 11 grams in pot 3, against only 10 grams in pot 1 without soil-extract.

The point of chief interest is, however, that there was twice, or more than twice, as much nitrogen in the above-ground growth in pots 2 and 3 with the soil-extract seeding, as in pot 1 without it. But there is much less difference in the amount of nitrogen remaining in the roots under the different conditions. In the total vegetable matter there is in pot 2 more than twice, and in pot 3 nearly twice, as much nitrogen as in pot 1 without the soil-extract.

With the full supply of already combined nitrogen in pot 4, with garden soil, there was about one and a third time as much dry substance produced, and more nitrogen assimilated, than under the influence of the soil-extract seeding.

The significance of the results relating to the nitrogen is, however, more clearly brought to view in the next table, which shows—the amounts in the soils at the commencement and at the conclusion of the experiment, and the gain or loss; the amounts in the seed, in the total products of growth, and the gain; the total nitrogen in the

soil and seed at the commencement, in the soil and produce at the conclusion, and the gain. Lastly, in the last column but one, the total gain, reckoning in each case, the initial nitrogen = 1; and, in the last column, the gain in the plants, reckoning the nitrogen in the seed = 1.

[The results relating to the soils in pots 1, 2, and 3, are calculated from the copper oxide determinations; which gave, in the dry sand at the commencement (as already shown) 0·00245 per cent. nitrogen; and at the conclusion the amounts were:—0·00269 in that of pot 1, 0·00239 in that of pot 2, and 0·00208 in that of pot 3. The determinations in the garden soil were by the soda-lime process, and were only made to obtain a general idea of the result, and were not intended for exact quantitative estimates of gain or loss. Thus, the higher the percentage of nitrogen, the smaller the quantity that can be taken for burning, whilst such a soil, rich from the application of dung, is a very heterogeneous mixture, and difficult to sample for analysis. It, moreover, contains a very large amount of carbon, and gives a coloured acid for titration. Nor was the nitric acid determined, either at the commencement or at the conclusion; but, with so much organic matter the error, if any, thus arising would be immaterial. The determinations were, however, fairly accordant for such material; giving, calculated on the dry soil, at the commencement, 0·4341 and 0·4379, mean 0·4360 per cent.; and at the conclusion, 0·4378 and 0·4342, mean 0·4360. It may be added, that a difference or error of 0·01 in the percentage of nitrogen in the soil, would represent a gain or loss of 0·204 gram on the quantity of the garden soil used. The data upon which the amounts of nitrogen in the seed, and in the products of growth, are calculated, have been already considered.—January 24, 1890.]

	Nitrogen.										
	In soil.			In seeds and produce.			Total.			In total products, total initial = 1.	In plants, nitrogen in seed = 1.
	At commencement.	At conclusion.	Gain (+) or loss (−).	In seeds sown.	In total plants.	Gain.	At commencement.	At conclusion.	Gain.		
	grams.	grams.	gram.	gram.	gram.	gram.	grams.	grams	gram.		
Pot 1...	0·0999	0·1096	+0·0097	0·0293	0·2822	0·2529	0·1292	0·3918	0·2626	3·03	9·63
Pot 2...	0·0999	0·0974	−0·0025	0·0298	0·5361	0·5063	0·1297	0·6335	0·5038	4·88	17·99
Pot 3...	0·0999	0·0848	−0·0151	0·0291	0·4357	0·4066	0·1290	0·5205	0·3915	4·04	14·97
Pot 4...	7·9989	7·9989	—	0·0301	0·6600	0·6299	8·0290	8·6589	0·6299	1·06	21·93

The first point to notice is, that there is very little difference in the amount of nitrogen in the soils at the commencement, and at the conclusion, of the experiments. There would, doubtless, be some

fine root-fibre not removed at the conclusion, so that where there is loss it is to be supposed that some of the original nitrogen of the soil has contributed to the growth. In the case of the garden soil, with its high percentage of nitrogen, it is of course not impossible that there may have been some loss by evolution of free nitrogen.

That there is at any rate no material gain in the soils would seem to be confirmatory of the conclusion indicated by other evidence, that the fixation of nitrogen is not effected by the organisms within the soil independently of the symbiotic growth of the nodules and their contents and the higher plant to which they are attached, to whose nitrogenous supply they seem to contribute. Indeed, if the fixation had taken place under the influence of microbes within the soil, independently of connexion with the higher plant, we should have to conclude that the latter had, nevertheless, availed itself of exactly the whole of the nitrogen so brought into combination—a supposition for which there would seem no reasonable justification.

Turning to the middle division of the table, which shows the nitrogen in the seed sown, in the total vegetable matter grown, and the gain, and disregarding the changes in the soil itself, which it has been seen may well be done, it will be observed that the gain of nitrogen in the plants is so large as to be very far beyond the limit of any possible experimental error. This certainly cannot be said of some of the experiments conducted on other lines, the results of which have been published in recent years, and been held to show the fixation of free nitrogen under the agency of micro-organisms within the soil, without coincident higher plant-growth, or with the coincident growth of other plants than of the leguminous family.

The gain in these initiative experiments with peas is, however, much less than in many of those of Hellriegel and Wilfarth. This is not to be wondered at, when the late period of the season, and the consequent character of the growth, are borne in mind; and when we come to consider the greater growth attained in the experiments of 1889, little doubt can be entertained that the fixation was then very much greater than it was in 1888.

To refer to the figures, it is seen that, whilst the nitrogen supplied in the seed was only 0·03 gram or less, that of the products of growth was 0·2822 gram in pot 1, 0·5361 in pot 2, 0·4357 in pot 3, and 0·6600 in pot 4; and the gains are $\frac{1}{4}$ of a gram in pot 1, more than $\frac{1}{2}$ a gram in pot 2, nearly $\frac{1}{2}$ a gram in pot 3, and more than $\frac{1}{2}$ a gram in pot 4.

The third division of the table shows—the total nitrogen at the commencement (in soil and seed together), at the conclusion (in soil and total vegetable matter grown), and the gains. But the significance of the results is more clearly seen in the last two columns. The first of these shows the relation of the amount of nitrogen in the total products (soil and plants together) to the total initial nitrogen (soil

and seed together), taken as 1. It is seen that, even in pot 1, with the impure and not sterilised sand, but without soil-extract, there was, so reckoned, more than three times as much nitrogen in the products as in the soil and seed; in pot 2, with soil-extract, there was about five times as much; and in pot 3, also with soil-extract, there was more than four times as much. In the case of pot 4, however, with garden soil, owing to the large amount of initial nitrogen in the soil, the gain, so reckoned, appears but small.

It is in the last column of the table, in which, disregarding the nitrogen in the soils, which remained so nearly constant throughout, and reckoning the relation of the nitrogen in the total products of growth to that in the seed taken as 1, that the large amount of fixation is brought clearly to view. So reckoned, the nitrogen in the substance grown was—in pot 1, 9½ fold; in pot 2, nearly 18 fold; in pot 3, nearly 15 fold; and in pot 4, nearly 22 fold, that supplied in the seed.

The Vegetation Experiments in 1889.

In this second season a more extensive series was arranged. The plants selected were—peas, red clover, vetches, blue lupins, yellow lupins, and lucerne. For the lupins and lucerne, specially made pots of glazed earthenware, about 6 inches in diameter, and 15 inches deep inside, that is about twice as deep as the pots used in 1888, and as used again for the peas, red clover, and vetches, were employed. These pots had holes at the bottom for drainage, and slits at the side, near the bottom, for aëration. All the pots stood in specially made saucers or pans of the same material. A quantity of broken, washed, and this time ignited flint, was put into the bottom of each pot. The sand used was a rather coarse white quartz sand, from which the coarser and the finer portions were removed by sifting, and more of the finer by washing and decantation, first with well, and afterwards with distilled water. In defect of means for igniting so large a quantity of material (about 300 lbs.) without running the risk of gaining more impurity than was expelled, the portion retained for use was kept, in successive lots, in a large water-bath, at nearly 100° C., for several days, and then preserved in well-closed bottles. The results will show that the sand so prepared was sufficiently, if not absolutely, sterilised.

In each case the sand was mixed with 0·1 per cent. of the plant-ash, and 0·1 per cent. of calcium carbonate.

There were four pots of each description of plant. Of the peas, clover, vetches, and lucerne, No. 1 was with the prepared quartz sand without soil-extract; No. 2 with the quartz sand and garden soil extract added; No. 3 was duplicate of No. 2; and No. 4 was with the garden soil itself. Of the blue and yellow lupins, No. 1 was with

the prepared quartz sand without soil-extract; No. 2 with lupin-soil-extract added; No. 3 was duplicate of No. 2; and No. 4 was with the lupin soil itself, to which 0·01 per cent. of the plant-ash was added.

The soil-extracts were in all cases added on July 9, before the sowing of the seed; 25 c.c. in the case of the peas, vetches, and clover, and 50 c.c. in that of the lupins and lucerne.

The seeds, carefully selected and weighed as in 1888, were sown on July 10, that is, about four weeks earlier than in the previous year, but still not so early as was desirable. In the case of the clover, ten seeds were sown in each pot; in that of the blue and yellow lupins three, and in that of the peas, vetches, and lucerne, only two seeds were put in each pot.

In all four pots, the peas germinated and grew well from the beginning. In the No. 1 pot of vetches, one seed failed and had to be replaced. Several of the red clover seeds failed, and eventually four plants only were left in each pot. As in 1888, most of the blue lupins failed; and eventually only one plant in only one of the four pots, remained. Some of both the yellow lupins and the lucerne also failed; but, as will be seen further on, eventually two good plants of each remained in each pot.

No analytical details relating to the experiments of 1889 are yet available; but the notes on growth, and the photographs of the plants and of their roots convey a clear idea of the importance and significance of the results obtained.

The peas were taken up on October 23 and 24. Photographs of the four pots of plants were taken on August 3, August 20, September 27, and October 22, that is the day before taking up; and an enlargement of the last taken is exhibited. It is seen that, unlike the result obtained in pot 1 in 1888 with the impure and non-sterilised sand, the plants in the purer and sterilised quartz sand, show extremely limited growth. Before the end of July, the plants in both pots 2 and 3, with soil-extract, began to show enhanced growth compared with that in pot 1, without soil-extract seeding; and eventually, whilst the plants in pot 1 were only $8\frac{1}{4}$ and $8\frac{1}{2}$ inches in height, those in pot 2 with soil-extract were 14 and $50\frac{1}{2}$ inches; and those in pot 3, also with soil-extract, were $52\frac{1}{2}$ and $50\frac{1}{4}$ inches high. In pot 4, with the garden soil, the plants showed even somewhat less extended growth than those in pots 2 and 3 with the soil-extract only. But the plants in pot 4 were more vigorous, and whilst they flowered and seeded, neither of those in either pot 2 or 3 did so; but continued to vegetate, the upper parts apparently at the expense of the lower.

The root development should be briefly noticed. In pot 1, without soil-extract, it was altogether much less than in either pot 2 or pot 3 with soil-extract, or than in pot 4 with garden soil. Enlarged photo-

graphs of the roots of pots 1, 3, and 4, clearly illustrate this. It is further seen that, in pot 1, without soil-extract, the main roots descended some distance before they threw out any considerable amount of root-branches and of root-fibre; whereas, in pots 2 and 3, with soil-extract, there was characteristically much more fibre distributed both in the upper layers and throughout the pot.

It is specially to be noted that, whereas in pot 1 in 1888, with impure and non-sterilised sand, there was a considerable development of nodules, now in the pure and sterilised sand, not a nodule was observable.

In pot 2, with soil-extract, one plant was very much larger than the other, and developed very much more root. The smaller plant had, however, several nodules on the main root, near the surface of the soil, and a good many small ones distributed along the fibres. Most of the nodules were more or less shrivelled. The larger plant had a large cluster of nodules on the main root, very near the surface; and a very large number of single nodules, mostly small, was distributed on the root-fibres, quite to the bottom of the pot. Upon the whole those on the larger plant were less shrivelled.

In pot 3, also with soil-extract, the main roots extended to, and along, the bottom of the pot; throwing off many side branches, with a very large quantity of fine fibrous root. The greatest distribution was, however, in the upper few inches of the soil. There were two clusters of nodules on one of the plants, and three on the other, besides smaller bunches. A large number of mostly single small nodules was also distributed along the roots. On one of the plants, the largest cluster was on the main root, and on the other the clusters were on the side branches.

In pot 4, with the garden soil, there was a dense mass of root-fibre throughout the first 6 inches of depth. There were numerous nodules, the majority single, and within the upper 2 or 3 inches of soil. There were also a few small bunches.

Thus, then, the limited growth in pot 1, without soil-extract, is coincident with the entire absence of nodule-formation; and the increased growth in pots 2 and 3, with soil-extract, is coincident with a very great development of nodules. In pot 4, with garden soil, itself supplying abundance of nitrogen, there was also a considerable development of nodules, but distinctly less than in pots 2 and 3, with soil extract only.

The vetches were taken up on October 26. They had been photographed on August 3, August 20, September 27, and lastly on October 25, that is, the day before taking up; and of this last representation an enlargement was exhibited.

Here, as with the peas, the plants in pots 2 and 3, with soil-extract, had shown more growth than those in pot 1 without it, before

the end of July. Again, as with the peas, the vetches in the pure and sterilised sand showed extremely limited growth. On the other hand, those in pots 2 and 3, with the soil-extract grew, as shown in the photograph, to a very great height; indeed, higher than those in pot 4 with the garden soil.

The heights of the plants were—in pot 1, without soil-extract, 11¼ and 10½ inches; in pot 2, with soil-extract, 52½ and 67 inches; in pot 3, also with soil-extract, 61½ and 51 inches; and in pot 4, with garden soil, only 53 and 36 inches.

But, as in the case of the peas, whilst the plants in pot 4 with the garden soil flowered and seeded, those in pots 2 and 3, with the soil-extract only, did not, but continued to extend upwards at the expense of the lower parts of the plant.

There was much less development of root in pot 1, without soil-extract, than in either pots 2 or 3 with it, or than in pot 4 with the garden soil. The main roots descended to the bottom of the pot, and threw out a number of side branches, but there was a marked deficiency of root-fibre. Not a single nodule was found.

In pot 2, with soil-extract, there was, as shown in a photograph, a dense mass of root and root-fibre, which distributed throughout the whole of the soil, though the greatest accumulation was within the first 3 inches of depth. There were numerous nodules, but considerably less in quantity than on the corresponding pea-plants. They were mostly single, the greater number being found in the lower layers, which is also contrary to the result with the peas. They were, moreover, generally exceedingly small.

In pot 3, also with soil-extract, there was also an immense development of root and root-fibre through the whole area of the soil; the greatest accumulation being in the upper and lower portions of the pot, with less in the middle. There were many nodules, but very small, and probably fewer than on the roots in pot 2. All the nodules were single, and fairly distributed over the whole root area.

In pot 4, with garden soil, there was a moderate amount of root and of root-fibre, chiefly within the upper 6 inches of depth; but there was altogether very much less of root development than in either pots 2 or 3 with the soil-extract. There were many nodules, but all single, and very small; and they appeared to be flattened, as if exhausted of their contents.

Here again, then, as with the peas, the very restricted growth in pot 1, without soil-extract seeding, was associated with very limited root development, and with the entire absence of nodule-formation. On the other hand, the very greatly extended vegetative growth in pots 2 and 3, with soil-extract, was associated with an immense development of root and root-fibre, extending throughout the pots, and with the formation of numerous nodules; which, however, were generally

smaller, more distributed over the whole root area, and less accumulated near the surface, than in the case of the peas. Lastly, in the garden soil, with its liberal supply of combined nitrogen, there was much less development of roots, and less also of nodules, than in the pots with soil-extract only.

Received January 21.

It has already been said that most of the blue lupins failed; but it was with the yellow lupins that the most striking results were obtained.

As in the case of the other plants, the yellow lupin seeds were put in on July 10, three being sown in each pot. There were some resowings, some seeds taken out, and, eventually, two plants were left in each pot. By the end of July those in pots 2 and 3, with the lupin-soil-extract seeding, already showed more growth than those in pot 1 without it. Photographs were taken on August 3, August 20, September 27, October 28, and November 29; and the plants were cut on December 7. An enlargement of the photograph taken on October 28 was exhibited; and the later representation, that of November 29, was thrown on the screen.

It is seen that the plants in pot 1, without soil-extract seeding, scarcely appeared over the rim of the pot, one being only about $1\frac{1}{2}$, and the other about $2\frac{1}{2}$ inches high. In pot 2, with lupin-soil-extract seeding, one plant was about 2 feet, and the other more than $1\frac{1}{2}$ foot high; both spreading much beyond the width of the pot. In pot 3, also with lupin-soil-extract seeding, one plant was more than 2 feet, but the other little more than 8 inches high. In fact, in both these pots with soil-extract seeding only, the plants showed considerably more development than those in pot 4 in the lupin-soil itself; one of these being only about 16, and the other about 18 inches high, and both less branching than those in pots 2 and 3.

Unlike the peas and vetches, the yellow lupins with soil-extract seeding flowered and podded freely. One plant in pot 2 had nine small pods; and one in pot 3, four large and three small ones. There were also in pot 4, with lupin-soil, on one plant five pods, and on the other six.

Thus, in the quartz-sand with lupin-soil-extract seeding, the plants not only produced a great deal more vegetable matter than those in the lupin-sand itself, but they as freely flowered and seeded.

Photographs of the roots of the plants in each of the four pots were taken; and enlargements of those in pot 1 without soil-extract seeding, in pot 3 with soil-extract seeding, and in pot 4 with the lupin-soil itself, were exhibited.

In pot 1, without soil-extract, and very restricted above-ground growth, there was coincidently very little root development. The main roots descended far down the deep pot almost without branching, but at the bottom a number of branches, and a mass of fibre were produced. The root-fibres were fleshy and succulent. No root swellings or nodules were found.

In pot 2, with the lupin-soil-extract seeding, there was, on the other hand, a very great development of root. Branches were thrown out throughout the whole length; and at their ends masses of fleshy fibrils were formed, which were thickly coated with root-hairs. On the main root of one plant, 3 inches down, there was a large swelling or nodule the size of a field bean; 4 inches lower there were three smaller ones on a side branch; 10 inches down there were three as large as peas; and lower still there was another small swelling, more like the nodules found on other plants. The other plant had less root growth. One and a half inch down there was a swelling the size of a small pea; and 4½ inches lower there were three swellings, one as large as a bean, and the others about the size of a vetch seed. These swellings on the lupin-roots, which were all on the main roots or thicker branches, are very different in appearance from the nodules on the pea and vetch-roots. They are, as described, swellings, encasing the root where they grow.

In pot 3, also with the soil-extract seeding, one plant, as an enlarged photograph shows, developed an immense amount of branching root, with a great deal of root-fibre, which extended throughout the whole soil, but to a greater degree in the lower than in the upper half of the pot. The main root was woody near the top. The lower root-fibres were fleshy, and thickly coated with root-hairs. There were several swellings or nodules on the main root below 5 inches; and lower down, on a root-branch, there were several swellings; there being in all twelve on this plant. On the smaller and more meagrely rooted plant, about 10 inches down, there were also two bunches of small nodules, and three single nodules; and a little lower, on a side branch, another small nodule. With regard to the great development of root-hairs on the fine fibrils of the roots in both pots 2 and 3, with quartz sand and soil-extract seeding, it may be supposed that this was an effort to acquire mineral nutriment, in quantity commensurate with the large amount of nitrogen fixed, and available to the plant.

In pot 4, with the lupin-sand, the distribution of root was very different from that in pots 2 and 3, with the soil-extract. The main root, at a depth of 2 inches, threw out many thread-like branches, at the end of each of which there was a bundle of fine fibre. The lower fibres became thicker, and were white and fleshy; but they were without the marked development of root-hairs observed in such

abundance in pots 2 and 3. Most of the root was within 6 inches of the surface, and there seemed to be none below 14 inches. One to two inches from the surface, there were swellings on the main roots which were less raised, but more spreading, than those on the roots in pots 2 and 3. There were also, on one side branch, six very small nodules.

To sum up in regard to the yellow lupins: Under the influence of the soil-extract seeding, the above-ground growth was not only very luxuriant, but the plants developed great maturing tendency, flowering and seeding freely. The development of the roots generally, and that of swellings or nodules on them, were also very marked; and there can be no doubt that the gain of nitrogen will be found to be very large. In pot 4, with the lupin-sand itself, which would supply a not immaterial amount of combined nitrogen, although the growth was normal, it was, both above ground and within the soil, very much less than in the pots with soil-extract only; and the development of nodules was also less. It is possible that the less development in the lupin-sand itself, than in the quartz-sand with soil-extract only, was partly due to the much less porosity of the lupin-soil, especially when watered. At any rate, the results with the soil-extract only are very remarkable.

As the main growth of red clover is in the second year, and that of lucerne also in years subsequent to the first, the pots of these plants are left for further growth; so that there is, at present, but little of definite result available in regard to them. There are, however, some points of special interest to notice.

A photograph of the clover plants taken on September 28 was thrown on the screen. The above-ground growth in pot 1, without soil-extract, was distinctly more than in either pots 2 or 3 with it; and it is judged that the amount of growth will probably prove to be greater than is to be accounted for by the amount of nitrogen supplied in the seed sown. As the soil-extract seeding in pots 2 and 3 seemed to be without effect, a second amount of extract, but this time from garden soil where clover was growing well, was, on September 4, applied to pot 2; but to pot 3 there was added instead a solution of calcium nitrate, and this application was continued up to December 6, when, in all, 0·23 gram of nitrogen had been so applied. The effect of the nitrate was, undoubtedly, some increased growth, but especially an increased depth of green colour. It remains to be seen what will be the final result.

The application of garden-soil-extract to lucerne also appeared to be entirely without effect up to the beginning of September; the plants in pot 1 without soil-extract, and those in pots 2 and 3 with it, showing no difference, and apparently no progress. On September 4, therefore, pot 2 was re-seeded with soil-extract, this time from a soil

growing lucerne; and, at the same time, a solution of calcium nitrate was added to pot 3, and the application was continued, as in the case of the clover. For many weeks the repeated soil-extract seeding was without any apparent effect; but, quite recently, there has been a slightly increased depth of colour, and perhaps a little growth. The application of nitrate to pot 3, however, showed marked effect very soon after the application had been commenced; and, as the representation of the growth on December 23 shows, there was up to that time, considerable growth under the influence of the nitrate.

The darkening of the colour of the leaves of the clover, and the increased growth of the lucerne, under the influence of the nitrate, in soil otherwise nitrogen-free, is of interest. Not that there is any want of abundant evidence showing that Leguminosæ do take up nitrogen largely as nitrate, but, in view of the new results under the influence of micro-organism seeding, it seems to be assumed by some that these plants probably depend for their nitrogen exclusively on such agency.

Before concluding in regard to the experimental plants, some reference should be made to the very great difference in the external appearance and character of the swellings, or nodules, on the roots of the different descriptions of plant, and even on those of the same description. In the course of the examinations this was so marked, that it was contemplated to take photographs illustrating the most characteristic differences; and, as it was found that the roots of the experimental plants, which had to be preserved for analysis, could not without risk be manipulated as required for the purpose, some plants were procured from the garden and the fields, and notes of previous observations were looked up. Presumably owing to the late period of the season, the roots so obtained were, however, not suitable for the illustration desired. It must suffice, therefore, avoiding any attempt at technical description, to make a few general observations on the facts at command; and to say that we hope to follow the subject up at a more suitable season of the year, and then to be able to give some account, not only of the general external, but, if possible, of the internal characters of the different bodies.

It should be stated that, so far as the nodules on the roots of the bean are concerned, a full technical description, both of their external characters and internal structure, has been given by Professor Marshall Ward ('Phil. Trans.,' B, 1887, vol. 178, p. 539, *et seq.*).

Reference to the descriptions which we have already given will show, that the external appearance, and distribution, of the nodules was very different on the roots of the peas, the vetches, and the lupins. In the case of the peas there were many of what may be called agglomerations of nodules, and comparatively few single ones distributed on the root-fibres. On the roots of the vetches, there

were comparatively few agglomerations or bunches, and more single nodules, pretty widely distributed along the root-fibres. The lupin roots, on the other hand, showed tubercular developments very different from those on either the pea or the vetch roots. Indeed, at the period of examination, that is when the plants were nearly ripe, two apparently distinct kinds were observed; one of which, the most prevalent, we have spoken of as "swellings," and the other as "nodules." The "swellings" were chiefly on the main roots or the thicker branches; where they grew they encased the root entirely, and they had a shining and presumably impervious skin. The "nodules," on the other hand, were chiefly single, small, and distributed on the root-fibres. Assuming that the so-called "swellings" were the bodies which, with their contents, had exercised the functions of the "nodules" found on the roots of the other plants, it is to be concluded that, after the very luxuriant growth, and the flowering and seeding, their function was so far at an end, and they had become suberised. The other bodies on the lupin roots, distinguished in the description as "nodules," indicated too meagre development to have had much share in the great amount of assimilation that had been accomplished. On the other hand, the "swellings," as has been said, were all on the main roots or thicker branches; whilst it is generally stated that the nodules are only formed on the young and still growing roots. If these "swellings," which were certainly very characteristic of the roots of the plants which attained the greatest growth, were really the effective nodules, it must be supposed that they had been formed where they were found, whilst the root was still young, and had grown with its growth. In favour of this supposition is the fact that the increased growth from the soil-extract seeding commenced quite early in the life of the plants.

In 1887, the nodule development on lucerne roots was observed at different periods of the season, and again quite recently, on plants taken from the field for that purpose. The nodules on the roots of lucerne are quite different in general external character from those on any of the other plants that have been examined at Rothamsted. Instead of being more or less rounded, they have more the appearance of shoots or buds, much longer than broad, sometimes single, but more often divided, or branched; there being generally two or three, and sometimes as many as twenty, or even many more, in a bunch, joined at the base. They have not been observed on the main root, but only on the root-fibres, and less near the surface than within the range of the clay subsoil. In some cases such a tuft or bunch will be at the end of a fine fibre by which it is connected with the main root. As the season advances these bodies become shrivelled, and are in fact empty shells. The question arises, whether in the case of the development in soil or subsoil containing organic nitrogen,

the lower organisms may not serve the higher, in part at least, by taking up, either directly or indirectly, combined nitrogen; as, for example, fungi take up organic nitrogen from the soil; or as, it may be assumed, does the fungus in the case of the fungus-mantle observed by Frank on the roots of Cupuliferæ, and some other plants?

Among the Leguminosæ growing in the mixed herbage of grass land, in 1868, nodules were observed on the root-fibres—of *Lathyrus pratensis*, especially near the surface of the soil; on the ultimate root-fibres of *Trifolium pratense*, and on the smaller rootlets of *Trifolium repens*.

In the case of red clover growing in rotation on arable land, an abundance of nodules has been found, both near the surface and at a considerable depth. They are generally more or less globular or oval. Some found on the main roots are more like "swellings" than attached tubercles, not, however, encasing the root, but only on one side. The greater number are, however, small, and distributed chiefly on the root-fibres. Observations are, however, needed, as to any difference in character, or relative prevalence, at different periods in the life and growth of the plant, and under different conditions of soil, both so far as mechanical state and porosity, and richness or otherwise in available supplies of combined nitrogen, are concerned. To these points we hope to pay some attention.

Referring to the main object of the investigation, it will be admitted that the results so far brought forward are abundantly confirmatory of those obtained by Hellriegel, and that the fact of the fixation of free nitrogen in the growth of Leguminosæ, under the influence of microbe seeding of the soil, and of the resulting nodule formation on the roots, may be considered as fully established.

It appears that, almost concurrently with the experiments made at Rothamsted, M. Bréal, of the Physiological Laboratory of the Muséum d'Histoire Naturelle, of Paris, has made various experiments on lines suggested by the results obtained by Hellriegel and Wilfarth. He examined the contents of nodules from lucerne roots, and observed rounded grains and bacteria-like filaments. He determined the nitrogen in the root-tubercles from various Papilionaceæ, and found it much higher in them than in the stalks, leaves, or roots. He germinated peas in a nutritive solution, and added some of the matter from a crushed lucerne root-tubercle. The pea roots became covered with tubercles, and eventually the nitrogen in the plant was about double that in the seed sown. In another experiment he germinated two lupin seeds, inoculated one of them from a living lucerne root-tubercle, and planted both in gravel with a nutritive solution free from nitrogen. Eventually the roots of the inoculated plant were covered with tubercles, whilst those of the other had

none. The inoculated plant also contained about two and a half times as much nitrogen as the seed, whilst without inoculation there was practically no gain. This experiment has been repeated by Hellriegel with very striking results, as one of us had the opportunity of seeing in August last. In another experiment, peas were germinated in a lucerne soil, transplanted into gravel, and nutritive solution free from nitrogen added, when the roots became covered with tubercles, and the nitrogen assimilated was nearly twenty-five fold that of the seed. On inoculating the germinated roots of haricots, and planting them in sand, they grew vigorously, formed pods, developed many tubercles on their roots, and assimilated nearly fifteen times as much nitrogen as the seed supplied. Lastly, he planted a fragment of lucerne root with nodules on it, in a sandy soil, reserving a similar fragment for analysis. Several cuttings of lucerne were obtained; and when taken up the root had many nodules, and the nitrogen assimilated was more than eighty times as much as in the root planted.

As to the importance to agriculture, in a quantitative sense, of this newly established source of nitrogen to the Leguminosæ, the evidence at present at command is insufficient to enable us to form any very decided opinion. Both agricultural investigation and direct vegetation experiment have clearly shown that Leguminosæ do take up much soil-nitrogen, and, at any rate in great part, as nitrate. But in our recent paper in the 'Philosophical Transactions' before referred to, we showed that, in some special cases, there was no evidence to justify the conclusion that the whole of the nitrogen had been so derived; and it was admitted that some other explanation of the large amounts of nitrogen assimilated was needed. It is not improbable that, in those cases, the agency now under consideration contributed to the result.

Then, as to the growth of leguminous crops in the ordinary course of agriculture. Hellriegel agrees with us that they do utilise soil-nitrogen, and he thinks probably always first; but that that source is supplemented by nitrogen brought into combination under the influence of the symbiotic growth of special organisms and the higher plant; and he supposes that the proportion of the total nitrogen assimilated which will be due to this latter source will be greater in crops grown in soils that are poor than in those which are rich in nitrogen. He considers it probable, however, that even in the case of rich soils there will be always more or less gain due to such fixation. The proportion of the nitrogen assimilated which will be gain depends, therefore, on complicated conditions. As bearing upon this subject it may be stated that, in experiments with beans, Professor Vines found that the formation of tubercles on the roots was very much reduced, if not indeed only accidental, when the plant was liberally supplied

with nitrate. Again, certainly the evidence of the experiments which have been described, so far as it goes, seems to indicate a less development of nodules when the soil contained an abundance of combined nitrogen. If this indication should be confirmed, and the inference be generally applicable, it would be concluded that the agency of the symbiotic growth supposed, in fixing free nitrogen, will, other things being equal, be the less the more the soil itself is in a condition to supply an abundance of combined nitrogen; whilst its capability in this respect will depend not only on the richness in combined nitrogen of the soil within the range of the roots, but on its state of combination, and on the character of the soil as to porosity and aëration. On the other hand, the development of the supposed nitrogen-fixing organisms obviously depends on the infection of the soil with the organism essential to symbiotic life with the particular leguminous crop to be grown. It would also seem that it is, at any rate in some cases, dependent on the due porosity and aëration of the soil.

Should these assumptions be borne out by the results of future investigation, we may conclude that the proportions in which any particular leguminous crop will derive its nitrogen from soil-supplies of combined nitrogen on the one hand, and from fixation under the influence of the symbiotic growth on the other, will be very different, according to the characters of the soil, as to available supply of combined nitrogen, mechanical condition, and due infection. We should further conclude that, in such cases as those in which poor sandy soils will not grow fair crops of cereals, but will nevertheless yield enormous crops of some leguminous plant—lupins, for example—the leguminous crop will depend for a large proportion of its nitrogen on fixation, under the influence of the symbiotic growth. Again, in such cases as those of the growth of lucerne for many years in succession, as in some Continental countries, it may be supposed that such fixation would be the source of a considerable proportion of the very large amounts of nitrogen assimilated over a given area under such conditions.

In the case of beans, there is evidence that there is nodule-formation when the plant is grown under ordinary conditions, in the garden or in the field; it has also been seen that nodules were formed on the roots of the peas and the vetches experimentally grown in garden-soil; and the inference so far is, that wherever there is such formation, there is more or less fixation.

Then, as to the important case of the growth of red clover in our rotations. There can be no doubt that red clover does avail itself of soil supplies of combined nitrogen. On the other hand, the so-called leguminous nodules have frequently been observed on the roots of red clover growing in the field. Further, although Hellriegel in his earlier experiments did not get definite results with clover, he has

subsequently obtained increased growth by seeding with extract from both a loamy humus-soil, and a root-crop-soil; but the result was less marked than with some other Leguminosæ. It has been seen that, in the first year of the experimental growth of clover at Rothamsted, no beneficial effect resulted from seeding with rich garden-soil-extract. It is believed, however, that the growth in the sterilised sand without soil-extract seeding will prove to be greater than can be accounted for by the supply of nitrogen in the seed sown. If this should turn out to be the case, the supposition will be that the necessary infection has come from the atmosphere. In reference to this point it may be mentioned that the glass-house in which the experiments are conducted stands in the midst of allotment gardens, in which a great variety of vegetables is growing, whilst Hellriegel's most definite result with clover was obtained by seeding with an extract from a root-crop soil.

Existing evidence is, therefore, in favour of the supposition that red clover does derive some of its nitrogen from fixation under the influence of proper soil-infection, and the resulting symbiosis of the lower and the higher growth. There is, however, at present very little definite evidence to guide us in judging under what conditions, on the one hand soil supplies of combined nitrogen, and, on the other such fixation, will contribute more or less of the total nitrogen of the crop. As one important element in forming a judgment on the subject, it is, as already said, our intention to study the conditions under which the development of nodules on the roots of growing clover is more or less favoured.

Upon the whole, then, the evidence at command points to the conclusion that, in the case of most if not all of our leguminous crops, a greater or less proportion of their nitrogen will be due to the fixation supposed.

Admitting the fact of such fixation to be fully established, the question still remains, how is it to be explained? Unfortunately, here again, as in the matter of the importance to agriculture in a quantitative sense, of this source of nitrogen to our crops, there is much yet to learn before a satisfactory answer can be given. Hellriegel frankly admits that a satisfactory explanation is still wanting; and we agree with him that we must know more of the nature and mode of life of the organisms which, in symbiosis with the leguminous plant, bring about the fixation of free nitrogen, before the nature of the action can be understood. As to the mode of life of these bodies, we owe much to the investigations of Marshall Ward, Prażmowski, Beyerinck, and others; but probably none will more readily admit than themselves, that the facts which they have established so far, are insufficient to afford an adequate explanation of the phenomena involved.

It is, it seems to us, a point of importance that it should be established, as it appears clearly to be, that in the development of the parasite the cortex of the host is penetrated, and so an intimate connexion between the two, indeed a symbiosis, is set up. Then there is abundant evidence that the nodules are very rich in nitrogen. So far as the facts at command go, it would seem that their dry substance may contain a higher percentage of nitrogen than that of any other part of the still growing plant; and, in some cases at any rate, even higher than in that of the highly nitrogenous leguminous seed itself.

Whence comes this nitrogen? The opinions of those who have specially studied the histology and biology of the subject, do not seem to be very clear or definite in reference to this point. According to Prażmowski, as quoted by Marshall Ward, the bacteroids "can only multiply in the still *living* protoplasm." Again, under the influence of the fungus—"the young tubercle is developed in the deeper parts of the cortex, and in its tissues the bacterium-like contents of the fungus become distributed, and grow, divide, and branch at the expense of the protoplasmic contents. He regarded the phenomenon as one of symbiosis, and as benefiting the host as well as the parasite." And again—"The tubercle-bacteria penetrate through young (not suberised) cell membranes into the root-hairs and epidermis cells of the root, and there multiply at the expense of the protoplasmic cell-contents."

Further, "The contents of the bacteroid cells are resorbed as the bacteroids dissolve, certain substances being left behind. In other words, the plant utilises the substance of the bacteria. When emptying begins, and with what energy it proceeds, depend especially on the quantity of nitrogenous compounds at the disposal of the roots. In a soil rich in nitrogen the tubercles go on developing unhindered, become large and typical, and rosy inside, and are not exhausted till late; in poorer soils they attain no great size, are soon emptied, and are green-grey inside."

Summarising the results and conclusions of Prażmowski, Marshall Ward says—

"No decision is arrived at as to whether the nitrogen is got from nitrogen compounds or from the free nitrogen of the air, nor as to what advantage accrues to the bacteria and the host-plant respectively." And again:—

"From the preceding, we see that the tubercles depend on a symbiosis which is advantageous to both the plant and the bacteria. The latter feed on the sap and cell-contents, and multiply through innumerable generations, and, both during the life of the host and afterwards, become redistributed in the soil. The plant derives advantage in that it obtains nitrogen by means of the bacteria.

Though the symbiosis is useful to both, the plant gains most, for it is the more powerful, and sooner or later overcomes the bacteria, to the multiplication of which it sets limits and finally absorbs the substance of the latter. Being the stronger, the plant directs the symbiosis."

If we understand the foregoing statements rightly, it is assumed that the bacteria acquire their nutriment, including their nitrogen, from the protoplasmic cell-contents of the higher plant; and that, on the other hand, the contents of the bacteroid cells are resorbed. "In other words, the plant utilises the substance of the bacteria." But it is obvious that, so far as the nitrogen of the bacteria is derived from the plant itself, the latter is not a gainer in a quantitative sense.

It is further assumed, that the activity of the process depends—"on the quantity of nitrogenous compounds at the disposal of the roots. In a soil rich in nitrogen the tubercles go on developing unhindered, become large and typical, ... in poorer soils they attain no great size, &c." Here, then, combined nitrogen in the soil is supposed to be the source of the nitrogen of the bacteria, and that they develop the more, the greater the supply of it. Undoubtedly, however, the nodules may develop very plentifully in a nitrogen-free soil, and there may be great gain of nitrogen, if only the soil be suitably infected. Indeed, the tendency of the evidence so far at command seems to show, that both the development of the nodules, and the gain of nitrogen, may be the greater in the poorer, but properly infected soil. Further, so far as the combined nitrogen of the soil is the source of the nitrogen there is no gain of it.

Marshall Ward says, however, that no decision is arrived at as to whether the nitrogen is got from nitrogen compounds or from the free nitrogen of the air, nor as to what advantage accrues to the bacteria and the host-plant respectively. But he adds that the symbiosis is advantageous to both the plant and the bacteria; the latter feeding on the sap and the cell-contents, whilst the plant obtains nitrogen by means of the bacteria.

It is obvious, however, that if the nitrogen of the bacteria is derived from the plant itself, it will be quantitatively no gainer by resorbing it. Nor would there be any such actual gain of nitrogen as there undoubtedly is, if the source of the nitrogen, either of the parasite or of the host, were essentially the supplies of combined nitrogen within the soil.

The most probable alternatives seem to be—1. That, somehow or other, the plant itself is enabled, under the conditions of the symbiotic life, to fix the free nitrogen of the atmosphere by its leaves; a supposition in favour of which there seems no evidence whatever. 2. That the parasite utilises and fixes the free nitrogen, and that the nitrogenous compounds formed are taken up by the host. On such a supposi-

tion, the actually ascertained large gain of nitrogen by the leguminous plant growing in a nitrogen-free, but properly infected, soil becomes intelligible. It is admitted, however, that further investigation of the mode of life of the parasite, especially having regard to its surrounding media, is needed.

It seems to us that there is nothing in the evidence pointing to the conclusion that the fixation is effected by the lower organisms within the soil independently of the symbiotic life. We do not here enter into the question, so much discussed of late, as to whether or not there is fixation within the soil under the influence of other low organisms, independently of the associated growth of a higher plant.

In our recent paper in the 'Philosophical Transactions,' before referred to, we said that whilst experience, whether practical or experimental, did not point to an unsolved problem in the matter of the sources of the nitrogen of the agricultural plants of other families, it was far otherwise so far as those of the Papilionaceæ were concerned. Further, that since the question of the sources of the nitrogen of the Leguminosæ had been the subject of experiment and of controversy for about half a century, and it was admitted that all the evidence that had been acquired on lines of inquiry previously followed had failed to solve the problem conclusively, it should not excite surprise that new light should come from a new line of inquiry; and, that hence should be recognised the importance of the cumulative evidence of the last few years, of which that furnished by the experiments of Hellriegel and Wilfarth was certainly the most definite and the most striking, pointing to the conclusion that although chlorophyllous plants might not directly utilise the free nitrogen of the air, some of them, at any rate, may acquire nitrogen brought into combination under the influence of lower organisms, the development of which was, apparently, in some cases a coincident of the growth of the higher plant whose nutrition they were to serve. It was added, that as such a conclusion was of fundamental and far-reaching importance, it was desirable it should be confirmed by independent investigation.

The results even so far obtained, and recorded in this paper, can leave no doubt that this important conclusion is confirmed, so far as a number of agricultural plants of the leguminous family are concerned. The question suggests itself, whether such, or allied agency, comes into play in the nitrogen assimilation of leguminous plants generally, or of that of other than the agricultural representatives of the non-leguminous families to which we owe such plants, or of those of the numerous and varied other families of the vegetable kingdom.

It is true that the families which contribute staple agricultural plants are but few, and that the agricultural representatives of those

families are also comparatively few. The families so contributing are, however, among the most important and widely distributed in the vegetable kingdom; as also are some of the plants they contribute. As prominent examples may be mentioned, the *Gramineæ*, affording the cereal grains, a large proportion of the mixed herbage of grass-land, and other products; also the *Leguminosæ*, yielding pulse crops, many useful herbage plants, and numerous other products. As we have said, there does not seem to be an unsolved problem as to the sources of the nitrogen of other of our agricultural plants than those of the leguminous family. Obviously, however, it would be unsafe to generalise in regard to individual families as a whole, from results relating to a limited number of examples supplied by their agricultural representatives alone. Still, there is nothing in the evidence at present at command, to point to the supposition that there is any fundamental difference in the source of the nitrogen of different members of the same family, such as is clearly indicated between the representatives of the leguminous, and of the other families, supplying staple agricultural products. On the other hand, existing evidence does not afford any means of judging whether or not similar, or allied agencies to those now under consideration, or even quite different ones, may come into play in the nitrogen assimilation of the members of other families which contribute such a vast variety of vegetation to the earth's surface.

We have pleasure in stating that the conduct of the investigation has largely devolved upon Dr. N. H. J. Miller. He has been almost wholly responsible for the analytical work, as well as for the photographing, by which a permanent record, not only of the above-ground growth, but of the root-development of the experimental plants has been secured. It should be added, that Mr. J. J. Willis has materially assisted in the observation and noting on growth; also in the separation of the roots, mounting them for observation and for photographing, and in noting upon them.

HARRISON AND SONS, PRINTERS IN ORDINARY TO HER MAJESTY, ST. MARTIN'S LANE.

THE FOOD OF OUR AGRICULTURAL CROPS.

If a person were asked what events had produced the greatest influence upon agriculture in Great Britain during the last half-century, he would, undoubtedly, say the establishment of the Royal Agricultural Society of England, and the publication of Baron Liebig's work upon agricultural chemistry. It is somewhat remarkable that these two events took place almost contemporaneously, the Royal Agricultural Society having been founded in 1838, and Baron Liebig's work published in 1840.

The first number of the Journal of the Society, which was issued in April 1839, contains an article "Upon the Present State of Agriculture as a Science in England," by the late Philip Pusey; and we may feel tolerably sure that this acute observer knew everything that was to be known in England on this subject. In speaking of bones as a manure, he says that farmers complain of the bones supplied to them having been previously boiled, and, consequently, that they have been fraudulently deprived of the oil they contained; with regard to which, Mr. Pusey suggests, with his usual sagacity, that the manuring properties of the bones are probably increased rather than diminished by the loss of the oil. Neither in Mr. Pusey's article, nor in an article by the Rev. W. L. Rham, "On the Analysis of Soils," published in the same Journal, and for which the author was awarded a prize of 20*l.*, do the terms phosphate, potash, nitrogen, ammonia, or nitric acid occur. These and a great number of similar terms which represent substances of the highest importance to agriculture, and which, to the farmers

of the present day, have become "household words," formed no part of the science of agriculture at the time Mr. Pusey wrote.

In accordance with the view generally entertained, Mr. Rham considered that the vegetable matter of the soil known by the name of humus was the source of its fertility. He says that real humus is a very complex substance, and suggests that our greatest chemists should make investigations into its nature. It was an immense step in advance when Boussingault, who was a most accurate chemist as well as a practical farmer, published analyses of the various crops grown upon his farm, and discussed the question of the fertility and exhaustion of the soil in connection with the export and restoration of definite chemical compounds. Having a considerable area of irrigated meadows attached to his farm, he considered that the hay grown on these meadows was sufficient to restore the ingredients exported from his arable land in corn and animal products, and his employment of what we now call artificial manures was confined to the application of gypsum to clover.

After the publication of Liebig's work, an immense number of experiments with artificial manures were carried out in this country. While some people recommended that the exact proportion of each ingredient exported from the farm in the produce should be returned in the artificial manure, others argued that only those substances should be returned which analysis of the soil proved to be wanting. The great battle, however, was over the employment of nitrogen. Being the most costly ingredient in an artificial manure, the necessity for its use became a question of great agricultural importance. Some contended that, provided the land was furnished with the necessary mineral ingredients, the plant could obtain all the nitrogen it required from the atmosphere; while others asserted that no amount of mineral food would prevent the yield from declining unless nitrogen in some form was used with the minerals. In an article published in the Society's Journal, Mr. Pusey summed up the conclusions derived from innumerable experiments in the following remark: "Ammonia for corn, phosphorus for roots," which, although not representing any scientific law, furnished in the simplest and plainest language a most valuable practical rule for farmers.

So little was known regarding the relation to the soil of some of the most important ingredients of growth, that, at the suggestion of an eminent chemist, a patent was taken out for fusing phosphate of lime and potash with other substances into a glass, to prevent them from being washed out of the soil; while at the same time some one else was bringing chemical action to

bear upon phosphates to increase their solubility. By degrees it became known that the three most important foods of plants—phosphoric acid, potash, and nitrogen—exist in the soil in a very insoluble form, and that by the action of the roots of plants the two former substances are dissolved, and taken up as food; while organic nitrogen, called humus by the older chemists, is the source of the nitric acid found in the water of the soil; and that, until the nitrogenous compound of the humus has become nitrified, it possesses comparatively small manuring properties. When it was found that the drainage-water taken from the soil when the crop is in the full vigour of its growth contains no nitric acid, while at all other times it does contain it in more or less quantities, there could no longer be any doubt that nitric acid is the chief source of the nitrogen in some of our crops, and that the necessity for the application of nitrogen in a manure depends upon the capability of the soil to liberate a sufficient amount of nitric acid to supply the wants of the crop. It is evident that nitric acid and its salts, such as the nitrates of soda, potash, and lime, being very soluble in water, and forming no fixed compounds with the soil, like phosphoric acid or potash, cannot accumulate; what is not taken up by the crops is more or less completely washed out during the winter. Each year, therefore, fresh quantities of nitric acid are formed, partly from the organic matter existing in the soil and partly from that supplied in the ordinary manures of the farm. The quantity available for the crop varies every year. For instance, after a very wet winter and spring a wheat crop may find very little left for its use when its active growth takes place in the spring, and must depend upon the amount liberated in the soil during its growth, or upon a direct application of nitrates.

The immense importance of dry weather in preventing the loss of nitric acid is well illustrated by the season of 1853–54. The wheat crop of 1854 was one of the typical great crops of the present century, the yield being very large upon all sorts of land, from the lightest to the heaviest; and yet, if we were to judge by the climate of the summer months, which are supposed to decide the yield of wheat, we should have expected that the crop would be below the average. May was cold and wet, June cold and sunless, July had not one day of summer heat, and the harvest was ten days or a fortnight later than usual. But now let us turn to the winter months of the same season. From seed-time to the end of April we find a great deficiency of rain, only half the average amount having fallen. In May there was a great excess of rain, which came

just when it was wanted, and was followed by less than the average rainfall during the next three months. This unusually large crop of wheat, grown under adverse summer conditions, can therefore only be accounted for by the fact that the large amount of nitric acid which was formed in the soil, and had accumulated there owing to the extremely dry weather prevailing from seed-time to harvest, was available for the use of the crop in the most important period of its growth. A great increase in the available nitric acid in the soil was evidently the cause, in the same year, of the exceedingly large yield of wheat (amounting to 21 bushels per acre) on our permanently unmanured land; for we know that at any time, by the application of nitrate of soda, the crops on this land can be increased by several bushels per acre.

The use of phosphates for root crops has sometimes led to the idea that these crops and the cereal crops do not obtain their nitrogen from the same source, and that the former are less dependent upon a supply of nitric acid in the soil. It is quite true that full agricultural crops of roots are frequently grown by the use of a manure which contains a soluble phosphate, and no nitrogen; but in these cases the soil must be equal to furnishing the amount of nitric acid required by the crop. It is known that the formation of nitric acid in the soil is much more rapid in the summer and autumn than at other times, and that constant stirring the soil so as to expose fresh surfaces to the air increases this formation. Root crops, beginning their active growth at the time when cereals are ripening, can obtain from the soil large quantities of nitric acid which were not available for the corn crops; the great exhaustion of the soil which follows the removal of a large root crop also proving that it obtains its nitrogen from the same source as the cereals. It is somewhat remarkable that maize, which is so largely grown in the United States, is said to be mostly benefited by the application of mineral manures, and to derive its nitrogen from the atmosphere, and not from the soil. Owing to the growth of maize taking place during the summer and autumn, it would, like our root crops, be less dependent upon a direct supply of nitrogen in manures; but, at the same time, it is reasonable to suppose that the source of the nitrogen in maize is the same as that of other cereal crops. So far as our crops are concerned, the evidence at our command points to the conclusion that our cereal crops, pasture-grasses, and various root crops, depend for their supply of nitrogen almost entirely upon the nitric acid in the soil.

There is a very important class of plants, included under the

general term "leguminous," which we find in more or less abundance in our permanent pastures, and which form part of our rotations. Some of these are annuals, some bi-annuals, some perennials; some are grown for their seeds, some for fodder; but, for whatever purpose they are grown, these plants possess properties which distinguish them from all others grown in rotation. In their stems, leaves, and seeds, they contain larger amounts of nitrogen than the other crops, while at the same time they do not respond to an application of nitrogen in manure, as do the other crops in a rotation. It is true, I have said, that under ordinary conditions of farming root crops can be grown without a direct application of nitrogen; but if we reduce the condition of the land by the removal of one or two of these, it will be seen that it is impossible to grow another heavy crop of roots without a very liberal supply of nitrogenous manure. No such result follows the application of nitrogen to a leguminous crop. If we apply a dressing of nitrate of soda to a mixed crop of rye-grass and clover, we can increase the rye-grass to almost any extent, but not the clover. There is no difficulty in growing full crops of grain or roots year after year upon the same soil, provided we use appropriate and sufficient manures; but no combination of manures has enabled us to grow continuous crops of red clover upon the same arable land; nor have our attempts to grow continuous bean crops been much more successful. So uncertain, indeed, has been the effect obtained by the application of various artificial manures to this class of crops, that farmers have generally come to the conclusion not to manure them, but to reserve the application of manures to those crops which can be depended upon to produce a profitable return.

Although the source of the nitrogen in leguminous plants has been the subject of scientific inquiries since the beginning of the present century, it is only since the various substances which constitute the food of plants have been produced in a separate form as chemical salts, and have been applied separately or combined to the various crops grown in rotation, that the distinctive character of the leguminous crops in regard to the effect of nitrogenous manures has been clearly brought out. There is no doubt that the great influence of such a substance as nitrate of soda upon corn crops and roots, and its want of effect upon leguminous crops, has led to the conclusion that the latter plants obtain their nitrogen from the atmosphere. Experiments carried out with the utmost care upon leguminous plants provided with abundance of mineral food only, and with air from which every compound of nitrogen had been extracted,

established the fact that, under these conditions, no increase of nitrogen in the plants takes place.

In Germany, in 1883, Hellriegel commenced some experiments with various plants in pots: he used washed sand with mineral manures, adding to some, but not to all, combined nitrogen, generally as a nitrate, and found that, with most of the plants, the increase of growth was in proportion to the amount of nitric acid supplied, but that the leguminous plants did not derive the same benefit from the nitrogenous manures as did the others. He then applied to his plants an extract from a fertile soil, and found that some of the leguminous plants, but not all of them, grew luxuriantly under this treatment: lupins, for instance, would not grow with the soil-extract. He then took an extract from a soil where they were growing luxuriantly, and obtained good growth. Again, if he sterilised the soil-extract so as to destroy the organisms in it, it ceased to be beneficial. Hellriegel found that the plants contained much larger quantities of nitrogen than there were in the soil-extract, while the amount in the plants was much too great to be attributed to errors of analysis. These experiments were so interesting and important that we considered it desirable to carry out some of a similar character, and this we have been doing for the last two years, confirming in every respect the results obtained by Hellriegel.

It appears probable that although the leguminous plants do not directly utilise the free nitrogen of the atmosphere, they do in some way obtain nitrogen from it through the medium of lower organisms, the development of which is, somehow, connected with the growth of the leguminous plants. The question which I now propose to consider is the bearing which these experiments have upon practical agriculture. Are we to suppose that the large quantity of nitrogen which these plants are known to contain has its origin in the atmosphere, and not in the soil? This is a very important question, as the opinion has already been expressed that we need not trouble ourselves about the source of the nitrogen in our leguminous crops, as it all comes from the atmosphere. Granting that the experiments recorded are perfectly trustworthy and correct—that, in the absence of nitrogen in the sand in which the seed is sown, and with a very minute amount of nitrogen supplied in the extract from a fertile soil, a gain of nitrogen in the plant takes place, we have still to inquire whether the same process goes on in an ordinary agricultural soil which contains nitrogen in more or less abundance.

In 1860, we published in the Society's Journal some experi-

ments upon the growth of red clover, the result of which showed that under no conditions of manuring could we continue year after year to grow this crop upon the same arable soil. A few years before this we had sown some red clover upon a piece of ground which had been used as a kitchen-garden for several centuries, and had, most probably, never before grown red clover. The first crops were exceedingly large, and the seed sown in 1854 did not require to be re-sown until 1860; and even now, at the end of thirty-six years, although the seed generally requires to be re-sown every two or three years, and the crops have become much smaller than they were at first, still they are quite as good as the ordinary farm crops, and the average yield over the whole period we estimate to have been nearly 3 tons of hay per acre per annum, and the amount of nitrogen carried off in the hay to have been 163 lb. per acre per annum. Samples of the soil were taken in 1857, and again in 1879—comprising twenty-one years of growth. The loss of nitrogen in the first nine inches was estimated at 2,732 lb. per acre; this was less by one-fourth than the quantity removed by the clover during that period. Unfortunately, in 1857 we did not take samples of the soil below the first nine inches; we are, therefore, unable to measure the loss which has taken place in the soil below this depth. As however, the subsoil is very rich in nitrogen, and the roots of clover are known to penetrate deeply into it, there can be very little doubt that the crop has taken nitrogen from this source, or that the soil is the real source of all the nitrogen removed in the crops. Notwithstanding the very large removal of nitrogen from this soil, it is still richer in this substance than the farm-land growing the permanent wheat crop, which has received 14 tons of farmyard dung per acre every year for the last forty-six years. This experiment is highly interesting, as proving that it is the want of food of the right sort in our farm soils which prevents our growing red clover more frequently upon them; it also shows that a vast amount of fertility may accumulate in a soil which has been used as a garden for a very long period.

Upon some old pasture-land mineral manures, but no nitrogen, have been applied every year since 1856. Under this application the crop of hay removed annually has been considerably larger than that removed from the unmanured land, and the effect of the minerals has been largely to increase the leguminous herbage, so that it constitutes about one-fifth of the whole crop; while upon the unmanured land not more than 8 per cent. is leguminous herbage. At the end of twenty years, careful analyses of the soil of both plots were made, and it was found that the first nine inches of the plot receiving the mineral

manures had lost upon the acre 506 lb. more nitrogen than the unmanured land; this would be equal to the annual loss of 25·3 lb. The analysis of the hay removed from the two plots showed that that of the mineral plot contained 23·6 lb. more nitrogen than the hay of the unmanured plot, a quantity corresponding very closely with the greater loss of nitrogen in the mineral manured soil. Too much reliance must not, however, be placed upon so complicated an operation as soil analysis, though the evidence points to the conclusion that the larger amount of nitrogen taken off the land by the leguminous herbage on the mineral plot was derived from the soil, and not from the atmosphere.

Although we found it impossible to grow red clover year after year upon the same arable soil of the farm, whatever might be the amount or composition of the manure applied, we found no difficulty in growing other leguminous plants upon the clover-sick land—the importance of which fact is very obvious, as it enables us to continue removing large quantities of nitrogen in leguminous crops year after year, instead of having to wait for some years until the land will again grow red clover.

It is evident, if the soil of our arable fields is the source of nitrogen, and the manures which we apply to them do not contain any, that, sooner or later, the stock of nitrogen in our soils will be greatly diminished; even to an extent which may eventually be measured by analysis. It is, unfortunately, the case that leguminous crops, such as lucerne, sainfoin, &c., which carry off the largest amount of nitrogen, are also those whose roots penetrate the deepest down into the subsoil; also, that the subsoil of my experimental fields varies in character so much, even where samples are taken with the utmost care, and at no great distance apart, that at present any comparative measurements of the loss of nitrogen in the soil are not to be trusted, and the experiments must be carried on for some years more before we can expect to give a satisfactory answer to this important question.

The general results of our experiments appear to show that while mineral manures, especially those containing potash, produce a large increase in leguminous crops, neither salts of ammonia, nitrate of soda, nor rape-cake, which furnish organic nitrogen, appear to have any decided influence upon them. This indicates a very distinct difference in the source from which the cereal and leguminous crops obtain their nitrogen; for, in the same field, and within a few feet of each other, nitrate of soda alone applied to the continuous barley crop has produced an average of 33 bushels per acre for thirty-six years in

succession. The absence of effect upon the leguminous crops from the application of nitrate of soda as a top-dressing is the more remarkable as analyses of the subsoil, where lucerne (the roots of which have penetrated nine feet from the surface) has been growing for some years, showed that considerable quantities of nitric acid had been removed; while upon a soil where white clover had been grown, the subsoil below the reach of the roots was much richer in nitric acid than it was within the range of the roots. Comparing these results with those on the adjoining soil and subsoil, where wheat and fallow had been under experiment for many years, there appeared to have been greater production of nitric acid in the soil where the white clover had grown than where the wheat grew; and, at the same time, the subsoil where the lucerne was growing was poorer in nitric acid than the subsoil of the white clover or of the wheat-land. In one year as much as 300 lb. of nitrogen per acre has been taken off in the lucerne, although the land has received no manure containing nitrogen for thirty years; while the wheat crop alternating with fallow cannot collect one-tenth of that quantity.

It would appear from these results, that during the growth and decay of leguminous crops considerable amounts of nitrates are formed and taken up by the plants, but the actual source of these nitrates is not yet clearly established. One-quarter of the adjoining field has grown continuous barley crops, nitrate of soda being used every year as a top-dressing; on the other three-quarters of the field barley is also grown, but red clover is occasionally sown with the barley upon one of these quarters, so that about once in eight years each of the three quarters has grown red clover instead of barley. The clover is made into hay, and carried off, and the barley which follows the clover receives no manure. The general result of this is, that the barley following the clover is quite as good a crop as the continuous barley manured with the nitrate of soda; and although the clover has carried away very much larger quantities of nitrogen than the barley, the first nine inches of the clover-soil shows by analysis a considerably larger amount of nitrogen than the barley-land. More nitrogen is carried off in the clover than in the barley, and more nitrogen is found in the top soil of the clover-land than in that of the barley; and this fact is quite in accordance with the experience of practical farmers, though they draw their conclusions from the increase of the succeeding crop, and not from analysis of the soil. We have hitherto, however, been unsuccessful in our attempts to ascertain if the increase of nitrogen in the top soil has been obtained by the clover from the subsoil.

Although an attempt to grow beans continuously in a field

set apart for that purpose did not fail so quickly, or from the same causes, as the experiments with red clover, still the result of thirty-two years' experience with beans established the fact that, under no condition of manuring could what might be called good agricultural crops be obtained year after year. It may be said that my land is not what farmers would call "bean-land;" still, it is heavy, with a clay subsoil, and at first it grew good crops. The land, however, appeared to get "tired" of the crop, and after thirty-two years' trial we considered that nothing more could be learnt by a continuation of this experiment. We therefore decided to sow the field with barley and red clover, having previously sampled and analysed the soil of the various plots with great care. Speaking generally, the soil had lost a good deal of its original fertility, and both the top soil and sub-soil were especially poor in nitric acid; agriculturally, the field might be said to have been "run out," and to have no condition left in it. The clover, which was sown with the barley, was so luxuriant that the growth of the latter was greatly impeded. The leaf was remarkable for its beauty, and had a colour which I had never before noticed in any ordinary field of clover. It was mown for hay the two following years, and yielded very luxuriant crops. Upon some portions of this field no manure of any sort had been applied from the commencement of the experiments in 1848, and in some years the beans would not return much more than the seed sown; and yet upon this same land very large crops of clover were grown, estimated to have removed 281 lb. of nitrogen per acre, while at the same time the nitrogen in the top soil had largely increased. Altogether, between the crop and the soil, something like 500 lb. of nitrogen are estimated to have been obtained from some source or other.

In 1848, some acres of land were set apart for experiments upon a rotation of crops. Part of this land has been kept entirely without manure, another part has received a mineral manure, and a third part has been highly manured with minerals, salts of ammonia, and rape-cake. The ordinary four-course rotation of turnips, barley, clover, and wheat, has been followed upon one-half of the experiment; and upon the other half the same crops have been grown, only excluding the leguminous crop, instead of which, a summer fallow has been taken, one of the main objects of these experiments being to ascertain the influence of a leguminous crop upon the other crops in a rotation as compared with a fallow. As it was found impossible to make the clover crop grow every fourth year, beans were substituted for it. Although we are now in the middle of the eleventh rotation, we are not yet able to give the information we

are seeking with regard to the influence of the leguminous crop, but some very valuable knowledge has been obtained. Altogether, six bean crops and four crops of red clover have been grown. Comparing the wheat which followed the beans with that which followed the fallow, it may be said that the latter was the better crop; and, the better the season for wheat, and the larger the general yield, the greater was the superiority of the fallow wheat. This was clearly shown in the year 1863, when the wheat crop was one of the largest ever grown in this country. The following table gives the produce of the wheat after a summer fallow and after a bean crop:

	Bushels per acre		
	Unmanured	Mineral manures	Highly manured
After fallow . . .	45	46	52½
After beans	34	34⅜	46
Fallow more than beans	11	11⅝	6½

This was the sixteenth year of the experiment, during which period the whole of the crops grown upon the land had been carried away. As we know with something like certainty that the yield of a wheat crop depends greatly upon the amount of nitric acid at its disposal in the soil, it appears probable that the large increase of the wheat crops upon the fallow-land, compared with the bean-land, was due to the beans having taken up nitric acid from the soil. In 1871, the wheat crop was as bad as that of 1863 was good. The yield upon the unmanured land after fallow was 11½ bushels per acre; after beans, 20½ bushels. Upon the land receiving minerals after fallow it was 16 bushels; and after beans, 24 bushels. The season was very wet; and though we may assume that a large amount of nitric acid was washed out of both the bean- and fallow-lands, the wheat upon the bean-land was benefited by the nitrification of the crop-residue of the beans, which would take place during the spring and summer.

It is somewhat remarkable that, upon land which has received no manure for forty years, and from which the whole produce upon it has been carried away, the average of ten crops of barley has been 30 bushels, and of wheat, 28½ bushels. While, therefore, grain crops can manage to find sufficient food in the soil to grow well, none of the so-called "restorative" crops could thrive. The turnips, after the first crop had been carried off, were little larger than radishes, and the next nine crops were valueless. The beans gave only 12 bushels per acre, while the clover in 1874, cut three times, only yielded 1¼ tons of hay, although no clover had been grown upon the land for twenty-

three years; the land which had been highly manured every fourth year giving 3½ tons of hay per acre. The wheat after the clover upon the unmanured land was a worse crop than that after the fallow.

From these results, it would appear that the roots and leguminous crops which we alternate with our corn crops are inferior to them in their capacity to collect their food from an unmanured soil; but when food is abundant, they have far greater power to make use of it than the cereal crops. In the 22 tons of swedes grown in 1880, and in the 4 tons of clover-hay grown in 1882 upon the manured rotation plot, much larger amounts of nitrogen and minerals would be found than in a cereal crop. The application of a mineral superphosphate of lime to the root crop every fourth year produced a very marked effect. The last ten crops of unmanured swedes were unable to produce a bulb, while the employment of superphosphate gave a produce of 7 or 8 tons per acre; the influence of the superphosphate was also very decided upon the clover crop, but not upon the beans. With regard to the main question, How far the mineral manure had enabled the leguminous plants to obtain their nitrogen from the atmosphere rather than from the soil, there is, however, at present no available evidence. The average of ten crops of wheat following fallow, and of ten following a leguminous crop, was identical—not quite 33 bushels per acre. Very careful samples of soil have been taken at different times from all the experimental plots, and analyses have been made of the total nitrogen in them, and also of the nitric acid; but although the results are of considerable interest, they do not show distinctly the differences we should expect to find in a soil which has not grown a leguminous crop for so many years, and one which has grown it every fourth year.

Samples of soil taken to the depth of 27 inches after a summer fallow gave considerably more nitric acid than similar samples taken from the land which had grown red clover; this, however, by no means proves conclusively that the clover had taken nitric acid from the soil, for more nitric acid might have been liberated in the fallow ground than in the clover ground. That food of some sort suitable to leguminous plants is accumulating in the fallow ground is shown by the difficulty we have in keeping them from growing on this ground: trefoil will come up, in more or less quantities, in the barley crop, where we cannot get at it; but two years out of the four, in the fallow and in the turnip crop, not a plant is allowed to grow. It creeps along the ground, and ripens its seed before the barley is cut, remaining dormant in the soil until the next corn crop

comes; and it has the same tendency to spread over the permanent wheat- and barley-ground. This fact, taken in connection with the luxuriant growth of the clover upon the field where the bean experiments had been carried on, seems to indicate the formation of some compound in the soil of which we are still ignorant, but which serves as food for leguminous plants. It is evident that this subject opens a wide field for special investigation, and it is fortunate that we possess samples of soil taken with great care from our various experimental fields at different periods, the history of which, in regard to the manures applied and the produce removed, has been recorded for a long series of years.

Although I have only referred to the experiments of Hellriegel upon the fixation of nitrogen by leguminous plants, and the repetition of these experiments by ourselves, numerous others upon the same subject have been carried out, in France, Germany, and the United States, which appear to prove that soils without vegetation fix large quantities of nitrogen; and also that, in those soils where plants not of the leguminous order have been grown, still more nitrogen is fixed. As a deduction from all these experiments, it has been argued that compensation must exist somewhere, otherwise the human race would, sooner or later, starve, owing to the exhaustion of the soil. If we accepted this idea, we should have to ignore the results of the last fifty years' experiments, and go back to the view expressed long ago, that plants can obtain all the nitrogen they require from the atmosphere, provided they are furnished with sufficient mineral food. As far as regards agricultural land under our ordinary grain or root crops, we have no evidence to show that the soil or the plant derives any appreciable amount of nitrogen from the atmosphere, beyond what is furnished by rain or dew. Where all artificial supplies of nitrogen in manures have been withheld for between forty and fifty years, and an abundance of minerals has been furnished, the yield of the crops is now so small, and the amount of nitrogen which they carry away bears so small a proportion to the quantity stored up in the soil within reach of their roots, that any exact comparison of the nitrogen carried off in the crops, and washed out of the soil by drainage, with the loss of nitrogen in the soil as determined by direct analyses, is hardly possible; but, as far as we can judge, the soil has lost about as much as the crop and drains have removed.

Turning again to the experiments on leguminous crops, we have in the garden soil evidence that red clover takes very large quantities of nitrogen from the soil—in fact, most probably the whole which the crop contains. On the other hand, we have the

experiment of sand containing no nitrogen, but supplied with minerals, and with a very minute quantity of nitrogen taken from a fertile soil, where leguminous plants have increased considerably in nitrogen. Interesting as these experiments are, they fail to explain the behaviour of leguminous crops in an ordinary agricultural soil. My garden soil is far higher in fertility than any which a farmer is likely to cultivate, unless he happens to farm one of the black soils of Russia; and he could not afford to cultivate a sand free from all vegetable matter and nitrogen, such as was used in the pot experiments. From the opposite results obtained in the garden soil and in the sand, are we to assume that the power of leguminous plants to obtain nitrogen from the atmosphere is dependent upon, and in proportion to, their inability to obtain it in sufficient quantity from the soil; and that it is only as soils become more and more exhausted of their fertility that this restorative process comes into force?

It is exceedingly difficult to account for the large crops of clover grown upon the unmanured bean-land. The amount of nitrogen taken up by the crop was very great, but it must not be forgotten that the quantity of mineral matter taken up was very much larger, as we may consider that the proportion in the clover-plant is about four parts of minerals to one of nitrogen. These minerals must have come from the soil, and must have accumulated there, in some form available for the clover, during the period when beans were grown upon the land. Whether at the same time some compounds of nitrogen suitable for the clover were also formed we have no evidence to show. An attempt to grow red clover last year where it was grown four years previously failed upon all the rotation experiments. We did succeed in growing it in 1886, after we had grown a large crop in 1882; but in the latter year there was a good deal of disease in the crop upon the highly-manured land, but none on the land which received only mineral manures.

From what I have said, it must be apparent that our knowledge at present of this important subject does not go beyond the facts that leguminous plants take nitrogen in large quantities from the soil, and that, under special conditions, they can obtain it from the atmosphere through the agency of micro-organisms; but we have no evidence to show that they do so when grown in the ordinary course of agriculture. The most probable means by which a solution of this problem can be arrived at, is to grow leguminous crops upon ordinary agricultural land with a liberal supply of mineral manures; in the course of time, the stock of nitrogen remaining in the soil must

decide the question one way or the other. It is very fortunate that so large an area in our various experimental fields has been kept free from all nitrogen in manures, and, had we known that land which had become "clover-sick" would grow other leguminous plants perfectly well, we should not have wasted twenty years in the hopeless attempt to grow clover, and we should have been in advance of our present position by the same period.

At the beginning of this paper I made a few remarks upon the position of agricultural science at the time of the publication of the first number of the Journal of the Royal Agricultural Society. Mr. Rham, in his prize essay, considered humus to be the chief source of fertility in soils; it is quite as much so now as it was then. He also said it was a complex substance, which should occupy the attention of chemists; and it has been the subject of investigations by them. It may now be desirable to pass in review, very shortly, the knowledge we have acquired regarding the food of our agricultural crops. Humus (in which term I include all vegetable matter in a certain state of decay) is very insoluble in water; but sooner or later, it assumes the form of nitric acid, which combines with lime or other alkaline substances in the soil, and then becomes very soluble in water. These compounds rise and fall with the water in the soil, coming to the surface in dry weather, and passing into the drains, in the absence of growing vegetation, in wet weather. When a crop is in the full vigour of growth, the soil-water may contain no nitrates, the crop having taken them all up; but at all other times the soil-water contains more or less nitrates. Being soluble in water, and entering into no combination with the soil, nitrates cannot accumulate. Each year fresh nitrates are formed from the decomposition of the humus, the fertility of land depending largely upon the amount of nitric acid liberated every year. What we call "condition," is so much added to the stock of organic matter, which in the course of a few years is decomposed, yielding nitric acid and mineral substances.

It appears probable that our grain and root crops take up the greater portion, or, perhaps, the whole of their nitrogen, in the form of nitrates, and, provided the necessary mineral food is in the soil, the growth of these crops depends upon the amount of nitric acid which is available. The great value placed upon nitrate of soda as a manure for corn crops is a sufficient proof that the necessary amount of mineral food exists in the soil. The main object of agriculture is to produce crops which yield large quantities of starch or sugar. In Great Britain, wheat, barley, oats, and potatoes yield the starch, and the root crops

the sugar; in other countries additional crops are grown, such as rice, maize, sugar-cane, sugar-beet, &c.; and it may be said that the amount of starch or sugar which we are able to produce upon a given area of land, depends greatly upon the amount of nitric acid which the crop can obtain from the soil. Mineral substances, however, are quite as essential to the growth of a crop as nitrogen, and, amongst these, phosphoric acid and potash are of the greatest importance. Lime is largely taken up by some crops; and where potash is deficient and soda is abundant, the latter substance, although it cannot take the place of potash in its most important functions, can at all events aid in promoting the growth of crops.

It is extremely important to understand clearly the capacity of our crops to obtain a supply of mineral food from the soil. In our four-course rotation, which has been kept entirely without manure for forty years, ten crops of wheat and ten of barley, grown in a rotation with swedes and a leguminous crop, have given an average yield of 28 bushels of wheat and 30 of barley. Each of these crops would carry off every year 15 to 20 lb. of phosphoric acid; that is, as much altogether as would be equal to 600 or 700 lb. of phosphate of lime. Between each crop of wheat and barley swedes are sown, but no bulbs will form, and the produce is only a few hundredweights per acre. It is evident that this crop cannot take up phosphate of lime from an unmanured soil, and that the growth of the swedes was arrested from the want of phosphates, and not from that of other substances, as the application of a mineral phosphate in the adjoining experiment was sufficient to produce a fair crop. Liebig suggested that the extension of the growth of root crops in Great Britain was due to a want of sufficient phosphates in the soil to grow more corn crops, analysis having shown that root crops contain less phosphates than corn crops. At the time Liebig wrote, the capacity of one crop to take an important food from the soil, and the inability of another crop to take it, was altogether unknown.

When we consider that cereal grain crops furnish by far the largest amount of food to the whole human race, we cannot but recognise how essential is the power which they possess—first, of obtaining so large an amount of their food from an ordinary unmanured soil, and, secondly, of growing continuously upon the same soil—neither of which properties is possessed by the other crops. The difficulty which root crops have of obtaining mineral food from the soil, has led to the idea that they are not dependent upon the soil for a supply of nitrogen, but can obtain it from the atmosphere. There is, however, every reason